Docket No. : IMRAA.015C1
Application No. : 09/785,944
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APPEAL BRIEF

Applicant	:	Martin E. Fermann
Appl. No	:	09/785,944
Filed	:	February 16, 2001
For	:	MODE-LOCKED MULTI-MODE FIBER LASER PULSE SOURCE
Examiner	:	Hrayr A. Sayadian
Art Unit	:	2815
Conf. No.	:	7227

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/SPR53538/
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Commissioner for Patents
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Sir:

Appellant, Applicant in the above-captioned patent application, appeals the final rejection of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 set forth in the final Office Action dated June 7, 2007 (hereinafter "the Final Office Action"). In accordance with the Notice of Appeal filed September 7, 2007, Applicant submits this Appeal Brief, accompanied by the fee set forth in 37 C.F.R. § 41.20(b)(2). Please charge any additional fees that may be required now or in the future to Deposit Account No. 11-1410.

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I. REAL PARTY IN INTEREST

The real party in interest in the present application is IMRA America, Inc., 1044 Woodridge Av., Ann Arbor, Michigan 48105. IMRA America is the assignee of record by virtue of the assignment attached hereto as Assignment Appendix XI.

II. RELATED APPEALS AND INTERFERENCES

No related appeals, interferences or judicial proceedings are currently pending.

III. STATUS OF CLAIMS

Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66, which are attached hereto as Claims Appendix VIII, are currently pending in the application and are the subject of this appeal. All of these claims stand rejected. Claims 9, 12, 27-29, 47-49, and 58 have been withdrawn, and Claims 34 and 51-54 have been canceled.

IV. STATUS OF AMENDMENTS

No amendments have been made in response to the Final Office Action.

V. SUMMARY OF CLAIMED SUBJECT MATTER

The present application includes two independent claims. Each independent claim is summarized below, with citations to corresponding portions of the specification and drawings as required by 37 C.F.R. § 41.37(c)(1)(v). These citations are provided to illustrate specific examples and embodiments of the recited claim language and are not intended to limit the claims.

Single-mode rare-earth-doped optical fiber amplifiers and lasers are widely-known. However, the amplification of high peak-power light in a diffraction-limited optical beam in single-mode optical fiber devices is generally limited by the small fiber core size that needs to be used to ensure single-mode operation of the fiber. Although amplification in multimode optical fibers had been considered at the time the parent of this application was filed, such amplification led to non-diffraction-limited outputs as well as unacceptable pulse broadening. Additionally, mode-locking of a multimode fiber laser was considered to be impossible.

The claimed subject matter of the present application relates to amplifying single-mode light pulses in a laser cavity that comprises a multimode amplifying fiber. Embodiments of the laser cavity design allow generation of high peak power light pulses from mode-locked multimode fiber lasers, which advantageously overcomes the peak power limitations found in conventional mode-locked single-mode fiber lasers. The cavity design can also be used to provide a mode-locked multimode fiber laser. Pump light may be coupled to the cladding of the multimode fiber for exciting a gain medium in the fiber, which provides energy for amplifying the light circulating in the cavity. Cladding pumping of the multimode fiber may permit much higher pump-light power to be input to the fiber, which advantageously results in much higher laser output power. Because modes in addition to the fundamental mode can propagate in the core of a multimode fiber, an optical guide (such as, e.g., a mode filter) may be positioned on the optical axis of the cavity to confine light amplified by the multimode fiber to preferentially the fundamental mode of the multimode fiber. Additionally, since commercial lasers may use a

relatively long length of amplifying fiber, the multimode fiber may be bent in order to advantageously fit long lengths of the fiber (e.g., as a coil) into a package having a commercially practical size.

Claim 1

Claim 1 is directed to a laser that comprises a cavity (see, e.g., page 9, lines 4-6; 11 in Fig. 1; 59 in Fig. 4; 75 in Fig. 5; 87 in Fig. 8; and 99 in Fig. 10) which repeatedly passes light energy along a cavity axis (see, e.g., page 9, lines 21-24; and 23 in Figs. 1, 4-6, 8, and 10). A length of multi-mode optical fiber (see, e.g., page 9, lines 7-20; 13 in Figs. 1, 4-6, 8, and 10-11; page 14, lines 13-20; Figs. 7A-7B) having a cladding (see, e.g., page 9, lines 14-17; Figs. 7A-7B) and doped with a gain medium (see, e.g., page 9, lines 7-8, 11-13; page 14, lines 11-12; Figs. 7A-7B) is positioned along the cavity axis (see, e.g., page 9, lines 21-24). A pump (see, e.g., page 7, lines 26-27; page 10, line 29 – page 11, line 3; 51 in Figs. 1, 5, 6, 10, and 11; and 69 and 71 in Figs. 4 and 8) is coupled to the cladding for exciting the gain medium (page 11, lines 1-3; page 12, lines 17-22). An optical guide (e.g., a mode filter such as the single-mode mode filter fiber 15 in Figs. 1, 4-6, and 11; page 9, line 17-20; and/or a fiber grating such as the Bragg grating in Fig. 10 and page 15, lines 4-11) is positioned on the cavity axis (23), which confines the light amplified by the multi-mode optical fiber (13) to preferentially the fundamental mode of the multi-mode optical fiber (see, e.g., page 7, lines 19-21; page 8, lines 25-29; page 14, lines 21-32; Figs. 9A-9C; and page 21, lines 3-9).

Claim 55

Claim 55 is directed to a method comprising circulating light energy (see, e.g., page 9, lines 21-24) within a laser cavity (see, e.g., page 9, lines 4-6; 11 in Fig. 1; 59 in Fig. 4; 75 in Fig. 5; 87 in Fig. 8; and 99 in Fig. 10). The method also includes amplifying the light energy (see, e.g., page 1, lines 3-6) within the laser cavity (11, 75, 99) in a bent multi-mode fiber (see, e.g., page 9, lines 10-11; 13 in Figs. 1, 4-6, 8, and 10-11). The method further includes confining the light energy within the laser cavity (11, 75, 99) substantially to the fundamental mode of the multi-mode fiber (see, e.g., page 7, lines 19-21; page 14, lines 21-32; and page 21, lines 3-9)

VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

The following grounds for rejection are to be reviewed on appeal:

1. The rejection of Claims 63-65 under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement.

2. The rejection of Claim 35 as being indefinite.

3. The rejection of Claims 1-4,7, 16-19, 22-26, 30-41, 46, 50, and 55-57 under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 5,627,848 to Fermann, et al. (hereinafter referred to as "Fermann III," using the Examiner's naming convention from the Final Office Action).

4. The rejection of Claims 1, 7, 8, 17, 18, 34-39, 46, 50, and 62-65 under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 5,422,897 to Wyatt et al. ("Wyatt").

5. The rejection of Claims 5, 6, 20, and 21 under 35 U.S.C. § 103(a) as being obvious over Fermann III.

6. The rejection of Claims 8 and 10-11 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of U.S. Patent No. 5,070,633 to Cohen et al. ("Cohen").

7. The rejection of Claims 13-15 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of Goldberg, et al., "V-Groove Side Pumped 1.5 micron Fiber Amplifier" ("Goldberg").

8. The rejection of Claim 42 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of either U.S. Patent No. 5,696,782 to Harter et al. ("Harter") or Galvanauskas, et al., "All-Fiber Femtosecond Pulse Amplification Circuit Using Chirped Bragg Gratings" (hereinafter "Galvanauskas I" using the Examiner's naming convention from the Final Office Action).

9. The rejection of Claims 43-45 under 35 U.S.C. § 103(a) as obvious over Fermann III in view of either Harter or Galvanauskas I, further in view of U.S. Patent No. 5,815,307 to Arbore et al. ("Arbore") and Galvanauskas, et al., "Fiber-Laser-Based Femtosecond Parametric

Generator in Bulk Periodically Poled LiNbO3" (hereinafter "Galvanauskas II" using the Examiner's naming convention from the Final Office Action).

10. The rejection of Claims 2-6, 19, 20, 21, and 30 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III, as motivated by De Souza, et al. "Saturable Absorber Modelocked Polarisation Maintaining Erbium-Doped Fibre Laser" ("De Souza").

11. The rejection of Claims 16, 22-26, 31-33, 40, and 41 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III.

12. The rejection of Claims 55, 57, 59-61, and 66 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III or in view of U.S. Patent No. 4,832,437 to Kim, et al. ("Kim").

13. The rejection of Claims 59-61 and 66 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III.

14. The rejection of Claim 56 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III or Kim, further in view of Fermann III.

15. The rejection of Claims 10-11 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Cohen.

16. The rejection of Claims 13-15 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Goldberg.

17. The rejection of Claim 42 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III, further in view of Harter I or Galvanauskas I.

18. The rejection of Claims 43-45 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III further in view of either Harter I or Galvanauskas I, further in view of Arbore and Galvanauskas II.

19. The statutory double patenting rejection of Claim 65 under 35 U.S.C. § 101 as claiming the same invention as Claim 64.

20. The nonstatutory obviousness-type double patenting rejection of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 as being unpatentable over the claims of U.S. Patent No. 5,818,630 to Fermann et al. (hereinafter "Fermann I" using the Examiner's naming convention from the Final Office Action).

21. The nonstatutory obviousness-type double patenting rejection of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 as being unpatentable over the Claims 1-4 of U.S. Patent No. 6,275,512 to Fermann (hereinafter "Fermann IV" using the Examiner's naming convention from the Final Office Action).

VII. ARGUMENT

For the reasons explained below, Appellant respectfully submits that the rejections in the Final Office Action are improper and requests that these rejections be reversed.

1. Rejection of Claims 63-65 under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement.

The Examiner contends Claims 63-65 contain subject matter not described in the specification as originally filed in such a way as to reasonably convey to one skilled in the relevant art that Applicant, at the time the application was filed, had possession of the claimed invention. Appellant respectfully submits that the Fermann I patent, U.S. Patent No. 5,818,630, which was expressly incorporated by reference in the present application as filed, provides support for Claims 63-65. Accordingly, the rejection is improper.

Discussion of Written Description Support for Claims 63-65

The Fermann I patent relates to the use of multimode fibers for amplification of laser light in a single-mode amplifier system. (Fermann I, col. 1, lines 7-9). The Fermann I patent also relates to continuous-wave lasers and pulsed lasers. (Fermann I, Abstract and col. 5, lines 4-8). The inventor of the present application, Martin E. Fermann, is one of the two named inventors of the Fermann I patent. The present application is related to the amplification of single-mode light pulses in multimode fiber amplifiers and lasers and builds on the prior work described in the Fermann I patent. The Fermann I patent is explicitly incorporated by reference in the present application as originally filed. (Page 2, lines 16-18). As courts have long recognized, by incorporating Fermann I by reference in the present application, Applicant explicitly ensured that all of the Fermann I patent was a part of the application "as if it were fully set out therein." *In re Lund*, 376 F.2d 982, 989, 153 U.S.P.Q. 625, 631 (C.C.P.A. 1967).

Dependent Claims 63-65 were added by amendment in a "Response to September 25, 2006 Office Action," filed on December 21, 2006 ("the Office Action Response"). Certain limitations

of Claims 63-65 (to be discussed below) were originally described in the Fermann I patent (which as noted was incorporated by reference). Accordingly, in the Office Action Response, Applicant also amended the present specification to bodily incorporate two sentences from Fermann I so that the present application would have literal support for these claim limitations. Because all of Fermann I is a part of the application "as if it were fully set out therein," *Lund*, 376 F.2d at 989, 153 U.S.P.Q. at 631, Appellant respectfully submits that this amendment to the specification is entirely proper.

The Examiner has rejected Claims 63-65 under Section 112, because the Examiner objects to the bodily incorporation of the two sentences from Fermann I as new matter. The Examiner contends that, because Fermann I was incorporated by reference in a section entitled "Background relating to optical *amplifiers,*" the bodily incorporation of material from Fermann I is out of context, because Claims 63-65 are directed to *lasers*. Appellant respectfully disagrees.

As noted above, both the Fermann I patent and the present application relate to amplification of laser light using multimode fibers. The "Field of the Invention" of the present application "relates to the amplification of single mode light pulses in multi-mode fiber *amplifiers*, and more particularly to the use of multi-mode amplifying fibers to increase peak pulse power in a mode locked *laser pulse source* used for generating ultra-short optical pulses." (Page 1, lines 3-6, emphasis added). Likewise, the Fermann I patent is related to the use of multi-mode fibers in amplifiers and lasers. (Fermann I, Abstract and col. 5, lines 4-8). Therefore, contrary to the contention by the Examiner, it is unambiguous that the context of the present application is related to the use of multimode fibers to amplify light pulses in both *amplifiers* and *lasers*. Because both Fermann I and the present application are related to multimode fibers in both amplifiers and lasers, a person of ordinary skill would find the teachings of the incorporated-by-reference Fermann I patent to be helpful in supplementing the teachings of the present application.

The Supreme Court has instructed that claims must be interpreted "in a way that comports with the instrument as a *whole*." *Markman v. Westview Instruments, Inc.*, 517 U.S. 370, 389 (1996) (emphasis added); see, also, *Phillips v. AWH Corp.*, 415 F.3d 1303, 1313, 75 U.S.P.Q. 2d

1321, 1326 (Fed. Cir. 2005) (*en banc*)(persons of ordinary skill read claims "in the context of the *entire* patent, including the specification.")(emphasis added). Accordingly, Appellant respectfully submits a person of ordinary skill would recognize that the teachings of the incorporated-by-reference Fermann I patent would be relevant to the subject matter of the claims of the present application. Therefore, Appellant respectfully submits that bodily incorporation of some (or all) of Fermann I into the present application is not out of context, is entirely proper, and cannot be considered to be new matter.[1]

Possession of the Inventions of Claims 63-65 by Martin E. Fermann

In rejecting Claims 63-65, the Examiner contends that the material added by amendment in the Office Action Response would not reasonably convey to a skilled artisan that Applicant, Martin E. Fermann, had possession of the claimed invention at the time the application was filed. Appellant respectfully disagrees.

Claims 63-65 depend from Claim 1 and include additional limitations originally described in the Fermann I patent. Claim 1 and dependent Claims 63-65 are the sole inventions of Martin E. Fermann. Applicant submitted a Rule 132 declaration with the Office Action Response establishing that to the extent the invention of Claim 1 was disclosed in the Fermann I patent, the invention was derived from Martin E. Fermann (a copy of the Rule 132 Declaration is attached hereto as Appendix 1). Because the Fermann I patent was incorporated by reference in the application as filed, Appellant respectfully submits there can be no doubt that Martin E. Fermann was in possession of the subject matter of Claims 63-65 at the time of filing.

Claim 63

Claim 63 recites a "laser as defined in Claim 1, wherein said length of multi-mode optical fiber has a V-value greater than about 2.5." Fermann I teaches that multimode fibers are more effective than single-mode fibers in amplifying light pulses to higher energies, and that in

[1] Further, the Patent Rules expressly permit incorporating by reference "essential material" from a U.S. patent that is necessary to provide Section 112 support. 37 C.F.R. § 1.57(c).

particular, multimode fibers with a V-value higher than 2.5 can be used for providing higher energies. (Col. 3, lines 10-13).

As discussed above, the rejection of Claim 63 is improper because Applicant properly incorporated by reference the disclosure of the Fermann I patent into the present application and clearly had possession of the invention of Claim 63 at the time of filing.

Claim 64

Claim 64 recites a "laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 3000." Fermann I teaches that to reduce mode coupling in order to provide a beam that is substantially in the fundamental mode, the number of modes should be in the range of 3 to 3000. (Col. 7, lines 6-13).

As discussed above, the rejection of Claim 64 is improper because Applicant properly incorporated by reference the disclosure of the Fermann I patent into the present application and clearly had possession of the invention of Claim 64 at the time of filing.

Claim 65

Claim 65 recites a "laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 1000." Fermann I teaches that to reduce mode coupling in order to provide a beam that is substantially in the fundamental mode, the number of modes should preferably be in the range of 3 to 1000. (Col. 7, lines 6-13).

As discussed above, the rejection of Claim 65 is improper because Applicant properly incorporated by reference the disclosure of the Fermann I patent into the present application and clearly had possession of the invention of Claim 65 at the time of filing.

Examiner Objections

Besides rejecting Claims 63-65 under Section 112, the Examiner has objected to the bodily incorporation of the material from Fermann I as new matter and has objected to labeling the present application as a continuation (rather than a continuation-in-part) of its parent application. As discussed above, Appellant respectfully submits that the amendments to the specification

made in the Office Action Response did not add new matter (and therefore do not require labeling this application as a continuation-in-part). Accordingly, Appellant respectfully requests that upon reversal of the Examiner's rejections of Claims 63-65, the Board instruct the Examiner to withdraw these objections.

The Examiner also objects to drawings filed on February 16, 2001 (the application filing date) but does not state in the Final Office Action what the objection is directed to. Appellant respectfully points out that in response to a Notice to File Corrected, Application Papers mailed by the Office on April 30, 2001, Applicant submitted substitute drawings in compliance with 37 C.F.R. § 1.84, and this submission was entered by the Office on May 21, 2001. Appellant respectfully submits the drawings on file are in compliance with the Office rules.

2. The rejection of Claim 35 as being indefinite.

Claim 35 depends from Claim 34, which was canceled from the application. Appellant respectfully offers to correct the dependency before issuance.

3. The rejection of Claims 1-4,7, 16-19, 22-26, 30-41, 46, 50, and 55-57 under 35 U.S.C. § 102(b) as being anticipated by Fermann III (U.S. Patent No. 5,627,848)

Claims 1-4,7, 16-19, 22-26, 30-41, 46, and 50 recite, among other limitations, a "multi-mode optical fiber," and Claims 55-57 recite, among other limitations, a "multi-mode fiber." The Examiner asserts that multi-mode fibers include "fibers that guide multi-modes, whether through the core *or within the cladding*" (emphasis added). Appellant respectfully disagrees with the Examiner's assertion that a multi-mode fiber includes a fiber with cladding-guided multi-modes. As will be discussed further below, the cited reference, Fermann III, does not disclose, either expressly or inherently, a multi-mode fiber as recited in these claims. Therefore, Appellant respectfully submits that the anticipation rejection is improper.

<u>Background on Single-Mode and Multi-Mode Optical Fibers</u>

The terms of a claim are to be given their "plain meaning," which is "the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention,

i.e., as of the effective filing date of the patent application." See *Phillips v. AWH Corp.*, 415 F.3d 1303, 1313, 75 U.S.P.Q. 2d 1321, 1326 (Fed. Cir. 2005) (*en banc*).

Appellant respectfully submits that when read in the context of the entire application, a person of ordinary skill would understand a multi-mode optical fiber to refer to an optical fiber comprising a *core* that can support propagation of modes in addition to the fundamental mode. The specification teaches that "a fiber is considered multi-mode when the V-value exceeds 2.41." (See, page 9, lines 8-9). As is well known in the art, the V-value (or normalized frequency) depends on the radius of the fiber *core* relative to the wavelength of light λ propagating in the core. The V-value also depends on the numerical aperture, NA, of the core. See, e.g., Fermann I, col. 6, Equation (1).

The Examiner cites the Federal Standard FS-1037C (Telecommunications: Glossary of Telecommunication Terms) to show definitions of terms in the technological arts. As Applicant stated in the Office Action Response, pages 12-13 (attached hereto as Appendix 2), the FS-1037C standard provides the following definition of "normalized frequency (V)" (emphasis added):

> **normalized frequency (V): 1.** In an optical fiber, a dimensionless quantity, V, given by
>
> $$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} ,$$
>
> where a is the <u>core</u> radius, λ is the wavelength in vacuum, n_1 is the maximum refractive index of the <u>core</u>, and n_2 is the refractive index of the homogeneous cladding. *Note 1:* In multimode operation of an optical fiber having a power-law refractive index profile, the approximate number of <u>bound modes</u>, *i.e.*, the mode volume, is given by
>
> $$\frac{V^2}{2}\left(\frac{g}{g+2}\right) ,$$

> where V is the normalized frequency greater than 5 and g is the profile parameter. *Note 2:* For a step index fiber, the mode volume is given by $V^2/2$. For single-mode operation, $V < 2.405$. Synonym V number.

Appellant respectfully points out that the teaching of the specification (see, e.g., page 9, lines 8-9) that multi-mode operation occurs for a V-value *greater* than 2.41 is consistent with the above definition of single-mode operation for V *less* than 2.405 (see, e.g., Note 2 in the definition above). Therefore, the FS-1037C standard shows that single-mode and multi-mode fibers are distinguished by light propagation properties of the fiber *core* and not light propagation within the fiber *cladding* as asserted by the Examiner.

Moreover, as described on page 13 of the Office Action Response (Appendix 2), the FS-1037C standard provides further support that fiber *core modes*, and not cladding modes, are used by persons of ordinary skill to distinguish between single-mode and multi-mode fibers. As indicated in Notes 1 and 2 of the above definition, the V-number is related to the number of "bound modes" in the fiber, which the FS-1037C standard defines as follows (entered on page 13 of the Office Action Response in Appendix 2):

> **bound mode:** In an optical fiber, a mode that (a) has a field intensity that decays monotonically in the transverse direction everywhere external to the <u>core</u> and (b) does not lose power to radiation. *Note:* Except for single-mode fibers, the power in bound modes is predominantly contained in the <u>core</u> of the fiber. *Synonyms* guided mode, trapped mode. (emphasis added)

Accordingly, bound modes represent propagating modes in the fiber *core,* and the number of such modes may be used to distinguish single-mode from multi-mode fibers. The number of propagating core modes can be determined from the V-number. Appellant respectfully submits that the FS-1037C standards clearly show that a person of ordinary skill would understand that a "multi-mode fiber" is characterized by the number of propagating *core* modes and *not* by the number of cladding modes (which the FS-1037C standard states are "undesired"; see, Office Action Response, page 13, in Appendix 2).

The Examiner cites U.S. Patent No. 4,829,529 to Kafka ("Kafka") to support his assertion regarding the scope of the recitation of "multi-mode fiber." Appellant respectfully disagrees with

the Examiner's characterization of Kafka. The fiber disclosed in Kafka (see, e.g., Figs. 1, 2, and 4) is known in the art as a doubly-clad (or double-clad) fiber defined by the FS-1037C standard as a "*single-mode* fiber that has two claddings" (emphasis added). (See, Office Action Response, page 13, in Appendix 2). Accordingly, contrary to the assertion of the Examiner, a person of ordinary skill would understand the fiber disclosed in Kafka to be a *single-mode fiber* and <u>not</u> a multimode fiber.

Additionally, during an interview with the Examiner on November 29, 2006 (summarized on page 9 of the Office Action Response attached as Appendix 2), Applicant's representatives discussed several well-known fiber optic reference sources that distinguish single-mode fibers and multi-mode fibers by the properties of propagating *core* modes, not cladding modes. These references were attached as Exhibits 1-5 of the Office Action Response, and are attached hereto as pages 27-51 of Appendix 2. These Exhibits also establish that cylindrically symmetric single-mode fibers and multi-mode fibers can be distinguished by the V-value of the *core* of the fiber. See, e.g., Exhibit 1, p. 10.10 (page 32 in App. 2); Exhibit 2, p. 317 (page 36 in App. 2); and Exhibit 4, p. 116-118 (pages 45-46 in App. 2).

For example, in "Fiber Optic Communications" by Joseph C. Palais (Exhibit 4 in Appendix 2), Section 5-4 "Modes in Step-Index Fibers" describes the propagation of modes of light in a circular step-index fiber. This reference establishes that the mode propagation characteristics of a fiber can be established in terms of the V-value. (See, page 45 in Appendix 2). The mode propagation chart in Figure 5-17 (page 45 in Appendix 2) allows the determination of the number of propagating modes in the fiber. Below a critical value of V=2.405, only a *single* mode can propagate in the fiber, whereas for larger values of V, multiple modes can propagate. For $V > 10$, the number of propagating modes is approximately $V^2/2$ (Equation 5-8 on page 45 of Appendix 2). Palais states, "[b]y using V, a *single* [mode propagation] chart can be drawn that applies for *any combination* of values" of core radius, wavelength, and fiber refractive indices. (See, page 45 in Appendix A, emphasis added). Therefore, this reference establishes that the mode propagation characteristics of *any* circularly symmetric step-index fiber depend on *core* properties (e.g., *core* radius) through the V-value, and the distinction between single-mode fibers

(one propagating mode) and multimode fibers (multiple propagating modes) is determined by the number of modes propagating in the *core* of the fiber.

The Examiner states that the prior art recognizes the existence of cladding modes in an oscillator and the need to strongly attenuate them. (Final Office Action, page 16). Appellants respectfully submit that the existence of cladding modes is irrelevant to the distinction between single-mode and multi-mode fibers. In "Handbook of Optics, Devices, Measurements, & Properties," attached hereto in Appendix 2, pages 28-32, the authors describe the classification of light rays in an optical fiber (see, e.g., Figure 4, reproduced below, and discussion related thereto on page 31 of Appendix 2).

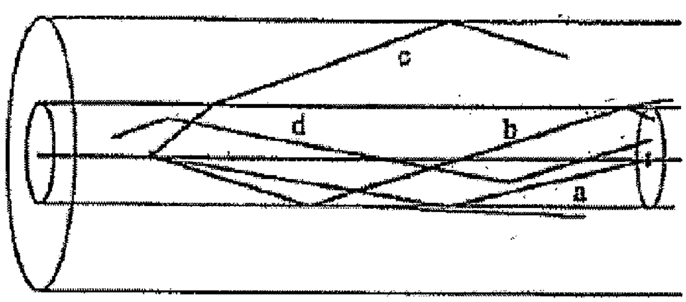

FIGURE 4 Classification of geometrical ray paths in an optical fiber. (*a*) Meridional ray; (*b*) leaky ray; (*c*) ray corresponding to a cladding mode; (*d*) skew ray.

Cladding modes, such as ray (c) in Figure 4 reproduced above, are "*not at all confined in the core*, but internally reflect off of the cladding-air (or jacket) interface." (Appendix 2, page 31, emphasis added). Appellant respectfully submits that if, as asserted by the Examiner, the classification of fibers as single-mode or multi-mode were based on the number of core *and* cladding modes, then there would be no such thing as a single-mode fiber, because even a fiber capable of propagating a *single* core mode may support one or more cladding modes. Accordingly, if the Examiner were correct, virtually *all* fibers would be classified as multi-mode fibers. This clearly is *not* how fibers are classified by persons of ordinary skill in the fiber arts. See, e.g., Equation (11) and surrounding text in the "Handbook of Optics" (App. 2, page 32), and the discussion of modes in step-index fibers in "Fiber Optic Communications" by Palais (App. 2, page 45).

The Examiner also contends that Claim 62, which recites a "multi-mode optical fiber [having] a V-value greater than about 2.41" means, by the Doctrine of Claim Differentiation, that the multi-mode optical fiber of Claim 1 may have a V-value "equal to or smaller than 2.41." (Final Office Action, page 4; see, also, page 16). Appellant respectfully disagrees with the Examiner's contention. Dependent Claim 62 has narrower scope than Claim 1, as required by 35 U.S.C. § 112, ¶ 4, because it recites the additional limitation quoted above. For example, Claim 62 may read on fibers having circularly symmetric cross-sections for which the V-value (defined above and in Fermann I) can be evaluated to be greater than about 2.41. See, e.g., the discussion in Section 2-1 entitled "Circular fibers" in "Optical Waveguide Theory," by Snyder and Love. (Appendix 2, page 34). Claim 1 would read on such fibers as well as on other multi-mode optical fibers (including, e.g., fibers having non-circularly symmetrical cross-sectional shapes, photonic crystal fibers, etc.) for which a V-value may not be readily defined.

In summary, Appellant respectfully submits that the plain meaning of the term "multi-mode optical fiber," as used in the specification, drawings, and claims, is a fiber comprising a <u>core</u> capable of propagating optical modes in addition to the fundamental mode. A fiber may be considered multi-mode if $V > 2.405$, with V determined by core properties (e.g., core radius). Moreover, the fiber optic references attached to the Office Action Response as Exhibits 1-5 also establish that a person of ordinary skill would understand the distinction between single-mode and multimode fibers to depend on the number of propagating *core* modes, rather than core plus cladding modes as contended by the Examiner.

<u>Fermann III Discloses *Single-Mode* Fiber</u>

The Examiner contends that Fermann III discloses multimode fiber. Appellant respectfully disagrees and submits that Fermann III instead discloses single-mode fiber. In particular, Fermann III discloses what is known in the art as a "double-clad" optical fiber that comprises a *single-mode core*. The properties of the core of the fiber disclosed in Fermann III are listed in column 4, lines 20-40: core diameter of 6 microns and numerical aperture (NA) of 0.16. Using these values, the V-value of the fiber disclosed in Fermann III is about 2, which is well below the upper limit (2.405) of the single-mode propagation regime. Accordingly, Fermann III discloses a

single-mode fiber and does not disclose multi-mode fibers as used in the specification and claims.

Applicant submitted the above calculation of the V-value of the fiber in Fermann III in the Office Action Response (see, page 14 in Appendix 2). In the Final Office Action, the Examiner did not comment on Applicant's calculation that $V \approx 2$, but instead made an *erroneous* calculation of the V-value (see page 7 of the Final Office Action). In this calculation, the Examiner correctly used the 6 micron core diameter disclosed in Fermann III. However, without providing any explanation for where the data was obtained, the Examiner *incorrectly* assumed that the square of the fiber's numerical aperture ($NA^2 = n_1^2 - n_2^2$) is 0.0588. Using this incorrect value, the Examiner erroneously determined V to be about 3 for the Fermann III fiber. However, Appellant respectfully points out that Fermann III explicitly discloses that NA=0.16 (col. 4, lines 22-23). Therefore, the value of NA^2 is about 0.026 rather than the value of 0.0588 erroneously adopted by the Examiner. Appellant respectfully points out that had the Examiner used the correct numerical aperture explicitly disclosed in Fermann III, the Examiner's calculation of the V-value of the fiber would have confirmed Applicant's calculation that $V \approx 2$ and would have confirmed that the Fermann III fiber is single-mode.

In summary, Appellant respectfully submits that Fermann III does not disclose a *multimode* fiber but rather discloses a *single-mode* fiber (with a V-value of about 2). With this background on single-mode and multimode optical fibers and on the teachings of the Fermann III patent, Appellant turns to the specific claims at issue.

Claim 1

Claim 1 recites a laser comprising, among other limitations, "a length of *multi-mode optical fiber*" and "an optical guide positioned on said cavity axis which confines the light amplified by said *multi-mode optical fiber* to preferentially the fundamental mode of said *multi-mode optical fiber*." As discussed above, Fermann III does not disclose a multi-mode optical fiber in a laser.

Therefore, Fermann III does not disclose each and every limitation of Claim 1, and the rejection is improper.

Claim 55

Independent Claim 55 recites a method comprising, among other limitations, amplifying "light energy within said laser cavity in a bent *multi-mode fiber*" and "confining said light energy within said laser cavity substantially to the fundamental mode of said *multi-mode fiber*." As discussed above, Fermann III does not disclose methods using multi-mode optical fiber.

Therefore, Fermann III does not disclose each and every limitation of Claim 55, and the rejection is improper.

Dependent Claims 2-4, 7, 16-19, 22-26, 30-33, 35-41, 50, and 56-57

Claims 2-4, 7, 16-19, 22-26, 30-33, 35-41, 50 depend from Claim 1 and Claims 56-57 depend from Claim 55. The dependent claims include all the limitations of the base independent claims, respectively, as well as additional limitations that define the scope of the inventions in these dependent claims. Because Fermann III does not disclose all the limitations of independent Claims 1 and 55, Appellant respectfully submits that the rejection of the dependent claims is improper. By declining to separately argue the dependent claims, Appellant does not imply that the limitations added by such claims are taught or suggested by Fermann III.

4. The rejection of Claims 1, 7, 8, 17, 18, 34-39, 46, 50, and 62-65 under 35 U.S.C. § 102(b) as being anticipated by Wyatt (U.S. Patent No. 5,422,897)

Claim 1

Claim 1 recites, among other limitations, "a pump coupled to said *cladding*" of a multi-mode optical fiber. Coupling the pump to the cladding of the multimode fiber permits much higher pump-light power to be input to the fiber, which advantageously results in much higher laser output power. Appellant respectfully submits that Wyatt does not disclose pump light coupled to the *cladding,* but rather pump light that is coupled to the multi-mode *core* of a single-clad fiber. (Wyatt, col. 1, lines 56-62; and col. 4, lines 52-64). For example, Wyatt teaches that the numerical aperture (NA) of the multimode fiber core should be large, e.g., by having "as high a value of Δn [refractive index difference between core and cladding] as possible to enable optimum coupling of light from the pump source into the multimode fiber." (Wyatt, col. 1, lines

59-62 and col. 5, lines 23-25). It is well known in the art that a large NA permits greater coupling of optical energy into the *core* of a single-clad fiber.

Wyatt also describes the use of a computer generated hologram (CGH) as an optical coupling means for coupling the pump power into the multimode fiber. (Wyatt, col. 6, lines 2-5). The CGH is used to convert the output of the pump (e.g., a laser diode array) "to a focused spot." (Wyatt, col. 1, lines 53-55). Such a focused spot provides good optical coupling to the *core* of the fiber.

Moreover, Wyatt teaches away from coupling pump light to the cladding. For example, Wyatt describes an example of a cladding-pumped double-clad fiber in which pump light is launched into an elliptical outer cladding of the fiber. (Wyatt, col. 2, lines 3-10). Wyatt describes the arrangement as having "an extremely complex structure, which makes fabrication very difficult." (Wyatt, col. 2, lines 6-7). Performance is "highly dependent on launch conditions" which are described as being "complicated." (Wyatt, col. 2, lines 8-10). To avoid these difficulties, Wyatt pumps light into the high-NA *core* of a multi-mode fiber. (Wyatt, col. 1, lines 59-62 and col. 5, lines 23-25). Thus, Appellant respectfully submits that Wyatt discloses a laser cavity that is *core*-pumped rather than *cladding*-pumped.

The Examiner admits that Wyatt discloses a coupling efficiency to the fiber *core* of about 50% (see the Final Office Action, page 16 and Wyatt, col. 6, lines 6-10). The Examiner then simply asserts, without citation to any teaching in Wyatt, that some of the pump light that is not coupled to the core is coupled to the cladding. Appellant respectfully disagrees with the Examiner's assertion. A person of ordinary skill in the optical arts will recognize that well known optical losses caused by, for example, absorption, reflection, refraction, scattering, diffraction, optical misalignments, etc., will lead to inefficient coupling of the pump light to the intended target (i.e., the *core* of the fiber in Wyatt's laser). Appellant respectfully contends that any (or all) of these well known optical losses may account for Wyatt's 50% core coupling efficiency. Since Wyatt does not expressly set forth that *any* pump light is coupled to the cladding, the burden is on the Examiner to provide evidence that a person of ordinary skill would recognize that pump light is *necessarily* coupled into the cladding in Wyatt's fiber laser. See, *In*

re Robertson, 169 F.3d 743, 745, 49 U.S.P.Q. 2d 1949, 1950-51 (Fed. Cir. 1999). Moreover, case law precludes reliance on "probabilities and possibilities," as the Examiner has done in the Final Office Action (pages 8, 16). See, *Continental Can Co. v. Monsanto Co.*, 948 F.2d, 1264, 1269, 20 U.S.P.Q. 2d 1746, 1749 (Fed. Cir. 1991). Appellant respectfully submits that the Examiner has not established that Wyatt teaches "a pump coupled to said cladding," and therefore the rejection of Claim 1 is improper.

Dependent Claims 7, 8, 17, 18, 35-39, 46, 50, and 62-65

Claims 7, 8, 17, 18, 35-39, 46, 50, and 62-65 depend from Claim 1 and include all the limitations of Claim 1 as well as additional limitations that define the scope of the inventions in these dependent claims. Because, as discussed above, Wyatt does not disclose all the limitations of independent Claim 1, Appellant respectfully submits that the rejection of these dependent claims is improper. By declining to separately argue the dependent claims, Appellant does not imply that the limitations added by such claims are taught or suggested by Wyatt.

5. The rejection of Claims 5, 6, 20, and 21 under 35 U.S.C. § 103(a) as being obvious over Fermann III

In rejecting claims under 35 U.S.C. § 103, the Examiner bears the initial burden of presenting a prima facie case of obviousness. See, *In re Fine*, 837 F.2d 1071, 1074, 5 U.S.P.Q. 2d 1596, 1598 (Fed. Cir. 1988). The Examiner must establish that all the claim limitations are taught or suggested by the prior art. See, *In re Royka*, 490 F.2d 981, 985, 180 U.S.P.Q. 580, 583 (C.C.P.A. 1974). If an independent claim is nonobvious, then any claim depending therefrom is nonobvious. *Fine*, 837 F.2d at 1075, 5 U.S.P.Q. 2d at 1598.

As set forth below, the Examiner failed to satisfy this burden with respect to each of the rejected claims.

Claims 5 and 6

Claims 5 and 6 depend from Claim 1 and include all the limitations of Claim 1 as well as additional limitations that define the scope of the inventions in these dependent claims. As discussed above in Ground of Rejection 3, Fermann III does not teach or suggest a "multi-mode

optical fiber" as recited in Claim 1. Accordingly, Fermann III does not teach or suggest all the limitations in Claims 5 and 6, which depend from Claim 1. Therefore, Appellant respectfully submits the rejection of Claims 5 and 6 is improper.

Claims 20 and 21

Claims 20 and 21 depend from Claim 1. The Final Office Action does not provide a separate basis for the rejection of Claims 20 and 21. To the extent the Examiner's basis for rejection Claims 20 and 21 is the same as for Claims 5 and 6, Appellant respectfully submit that the rejection is improper for substantially the same reasons explained above.

6. The rejection of Claims 8 and 10-11 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of Cohen (U.S. Patent No. 5,070,633)

Claim 8

Dependent Claim 8 recites a laser as defined in Claim 1, "wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber." As discussed above in Ground of Rejection 3, Fermann III does not teach or suggest a "multi-mode optical fiber" as recited in Claim 1 or claims depending therefrom. The Examiner relies on Cohen for teaching fusion splicing and tapering fibers but has not identified any teaching related to a "multi-mode optical fiber." Therefore, the combination of Fermann III and Cohen does not teach or suggest all of the limitations of independent Claim 1 or dependent Claim 8. Therefore, Appellant respectfully submits the rejection of Claim 8 is improper.

Additionally, Appellant respectfully disagrees that Fermann III and Cohen, singly or in combination, teach a "single-mode mode-filter fiber [that] is fusion spliced onto one end of said multi-mode optical fiber." Appellant respectfully submits that Cohen describes a fusion splice between two single-clad fibers, which are "typically *single-mode fibers*." (Cohen, col. 4, lines 20-21, emphasis added). The Examiner contends that Cohen teaches fusion splicing fibers with significantly different single-mode core diameters and suggests this teaching should apply to the multimode fibers of Claim 8 (and Claims 9-11) because "the multimode nature of modes is not limited to the core." (See the Final Office Action, page 16). Appellant respectfully disagrees,

because as discussed above, the multimode fiber recited in these claims comprises a multimode, rather than a single-mode, core. Accordingly, Fermann III and Cohen do not teach or suggest the laser of Claim 1, "wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber."

Claims 10 and 11

Claims 10 and 11 depend from Claim 8 and include all the limitations of Claim 8 as well as additional limitations that define the scope of the inventions in these dependent claims. Because, as discussed above, Fermann III and Cohen do not teach or suggest all the limitations of Claim 8, the rejection of Claims 10 and 11 is improper in view of their dependency from Claim 8.

7. The rejection of Claims 13-15 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of Goldberg

Claim 13

Dependent Claim 13 recites a laser as defined in Claim 1, "wherein said pump is coupled to the side of said multi-mode fiber." As discussed above in Ground of Rejection 3, Fermann III does not teach or suggest a "multi-mode optical fiber" as recited in Claim 1 or claims depending therefrom. The Examiner relies on Goldberg for teaching v-groove side pumping but has not identified any teaching in Goldberg for "multi-mode optical fiber." Therefore, the combination of Fermann III and Goldberg does not teach or suggest all of the limitations of independent Claim 1 or dependent Claim 13. Therefore, Appellant respectfully submits the rejection of Claim 13 is improper.

Additionally, the Examiner cites the Goldberg reference for teaching v-groove side pumping. However, Goldberg teaches forming a v-groove on a fiber having a *single-mode* core (see, Goldberg, p. 208) and not "a v-groove on said *multi-mode* optical fiber for coupling said pump to said multi-mode fiber." Therefore, for this additional reason, Appellant respectfully submits the rejection of Claim 13 is improper.

Claims 14 and 15

Claims 14 and 15 depend from Claim 13 and include all the limitations of Claim 13 as well as additional limitations that define the scope of the inventions in these dependent claims. Because, as discussed above, Fermann III and Goldberg do not teach or suggest all the limitations of Claim 13, the rejection of Claims 14 and 15 is improper in view of their dependency from Claim 13.

8. The rejection of Claim 42 under 35 U.S.C. § 103(a) as being obvious over Fermann III in view of either Harter (U.S. Patent No. 5,696,782) or Galvanauskas I

Claim 42

Claim 42 recites a laser as defined by Claim 1 (through intermediate dependencies of Claims 40 and 41) which additionally comprises "an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity." As discussed above in Ground of Rejection 3, Fermann III does not teach or suggest a "multi-mode optical fiber" as recited in Claim 1 or claims depending therefrom. The Examiner relies on Harter and Galvanauskas I for teachings related to output couplers but has not identified any teaching or suggestion in Harter or Galvanauskas I related to "multi-mode optical fiber." Therefore, the combination of Fermann III and Harter or Galvanauskas I does not teach or suggest all of the limitations of independent Claim 1 or dependent Claim 42. Therefore, Appellant respectfully submits the rejection of Claim 42 is improper.

9. The rejection of Claims 43-45 under 35 U.S.C. § 103(a) as obvious over Fermann III in view of either Harter or Galvanauskas I, further in view of Arbore (U.S. Patent No. 5,815,307) and Galvanauskas II

Claims 43-45

Claim 43 depends from Claim 42, Claim 44 depends from Claim 43, and Claim 45 depends from Claim 44. As discussed above in Ground for Rejection 3, Fermann III does not teach or suggest "multi-mode optical fiber" as recited in these dependent claims. The Examiner does not

cite any of the listed references (Harter, Galvanauskas I or II, or Arbore) as teaching or disclosing this limitation. Therefore, the cited references, either alone or in combination, do not teach or suggest all the limitations of Claims 43-45. Appellant therefore respectfully contends that the rejection is improper.

10. The rejection of Claims 2-6, 19, 20, 21, and 30 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III, as motivated by De Souza.

Claims 2-6, 19, 20, and 21

These claims depend from and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above in Ground for Rejection 4, Appellant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1 and claims depending therefrom. Therefore, Appellant respectfully submits that the Examiner has not established a prima facie case of obviousness, because the cited references, alone or in combination, do not teach or suggest all the limitations of the rejected claims. The rejection of Claims 2-6, 19, 20, 21, and 30 is improper.

The rejection of these claims is improper for additional reasons. For example, Claims 2-6 and 19-21 include "a mode locking mechanism positioned on said cavity axis." The Examiner admits that Wyatt does not teach or suggest modelocking. (See, Office Action mailed September 25, 2006, page 16). Appellant respectfully submits that the Examiner has not established that, even if Wyatt, Fermann III, and De Souza were combined, there would be a reasonable expectation of success of modelocking the laser recited in these claims. See, *In re Rinehart*, 531 F.2d 1048, 1053-54, 189 U.S.P.Q. 143, 148 (C.C.P.A. 1976). For example, to the extent that Fermann III and De Souza disclose modelocking, it is in the context of *single-mode* fibers and not *multi-mode* fibers as recited in this application's claims. The present application teaches that the stability of modelocking depends on reducing spurious reflections in the oscillator, which are conceptually equivalent to mode-coupling in multi-mode fibers. (Application, page 6, lines 29-

31). The application also teaches that mode-coupling of higher order modes in a multi-mode fiber *suppresses* mode-locking. (Id.; see, also, Fermann III, col. 5, lines 38-60). In fact, as of the filing date of the application, modelocking of a *multi-mode fiber* was considered "impossible." (Application, page 7, line 12). Accordingly, Appellant respectfully submits that the Examiner has not demonstrated that even if a person of ordinary skill combined the teachings of Wyatt, Fermann III, and De Souza, which relate to modelocking in a *single-mode* fiber, the person of ordinary skill would be capable of achieving modelocking in a *multi-mode fiber,* which, as noted, was considered to be "impossible" at the time the application was filed. See *Dystar Textilfarben GmbH & Co. Deutschland KG v. C.H. Patrick Co.*, 464 F.3d 1356, 1360, 80 U.S.P.Q. 2d 1641, 1651 (Fed. Cir. 2006).

In the Final Office Action, the Examiner contends that Applicant's statement in the application that "no stable operation of a mode-locked multi-mode fiber laser has yet been demonstrated" (page 7, lines 12-13) amounts to a "tacit admission that unstable mode-locking was demonstrated." (Final Office Action, page 17). The Examiner further contends that the rejection is proper, because "the claims are not limited to 'stable' versus unstable mode-locking." (Id.). The Examiner's contentions are simply without merit. The application makes clear that the disclosed lasers "allow the *stable* generation of high peak power pulses from mode-locked multi-mode fiber lasers." (Page 7, lines 17-18, emphasis added). Even accepting, for argument only, that *unstable* modelocking had been previously demonstrated, the Examiner has not established an "apparent reason" why a person of ordinary skill would combine references teaching only *unstable* modelocking in order to achieve the inventions in these claims. See, *KSR Intern. Co. v. Teleflex Inc.*, 550 U.S. __; 127 S.Ct. 1727, 1741 (2007). Further, Appellant respectfully submits that the Examiner's mere contention that *unstable* modelocking may have been demonstrated simply does not meet the Examiner's burden to provide evidence that a person of ordinary skill in possession of the cited Wyatt, Fermann III, and De Souza references would have the technical capability to achieve *stable* modelocking in a laser comprising a multimode optical fiber. See, e.g., *Dystar*, 464 F.3d at 1360, 80 U.S.P.Q. 2d at 1651.

Appellant also submits that a person of ordinary skill, upon reading the entire application, would recognize that Applicant's disclosure of a laser that allows "the stable generation of high peak power pulses from mode-locked multi-mode fiber lasers" fulfills "long felt, but unsolved needs," since mode-locking of a multimode fiber had been considered "impossible" at the time of filing the application. See, *Graham v. John Deere Co.*, 383 U.S. 1, 17 (1966). Accordingly, Appellant submits that this "secondary consideration" is strong evidence of the nonobviousness of the claimed inventions. *Id.*

Claim 30

Claim 30 recites a laser as defined in Claim 1 "configured to generate ultra-short optical pulses, wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec."

Claim 30 depends from and includes all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in this claim. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above in Ground for Rejection 4, Appellant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1 and claims depending therefrom. Therefore, Appellant respectfully submits that the Examiner has not established a prima facie case of obviousness, because the cited references, alone or in combination, do not teach or suggest all the limitations of Claim 30. The rejection of Claim 30 is improper.

The rejection of this claim is additionally improper, because the Examiner has not established that the cited references, alone or in combination, teach or suggest other limitations of Claim 30. The Examiner simply states that production of short pulses can be initiated by a mechanism having short and fast recovery (the Final Office Action , page 12), but does not establish, for example, that the combination of references teaches or suggests the ultra-short optical pulses are "preferentially in the fundamental mode of said multi-mode optical fiber."

11. The rejection of Claims 16, 22-26, 31-33, 40, and 41 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III

Claims 16, 22-26, 31-33, 40, and 41

These claims depend from and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above in Ground for Rejection 4, Appellant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1 and claims depending therefrom. Therefore, Appellant respectfully submits that the Examiner has not established a prima facie case of obviousness, because the cited references, alone or in combination, do not teach or suggest all the limitations of the rejected claims. The rejection of Claims 16, 22-26, 31-33, 40, and 41 is improper.

12. The rejection of Claims 55, 57, 59-61, and 66 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III or in view of Kim (U.S. Patent No. 4,832,437)

Claim 55

Independent Claim 55 is a method including, among other limitations, "amplifying said light energy within said laser cavity in a bent multi-mode fiber." Since commercial embodiments of lasers may use a relatively long length of fiber (e.g., longer than about 1 meter; see, application, page 9, lines 7-8), bending the fiber advantageously permits fitting the fiber (e.g., as a coil) into a package having a commercially practical size. The Examiner admits that Wyatt does not disclose bending a multi-mode fiber. (Office Action mailed September 25, 2006, page17). Appellant respectfully submits that Wyatt strongly teaches away from bending multi-mode fiber, because bent multi-mode fiber causes "significant coupling of power into higher order modes." (Wyatt, col. 7, l. 4-5 and 57-60). Such mode coupling makes it "difficult to control the amount of optical energy that exists in any single mode at any given time." (Wyatt, col. 6, l. 67-68). To avoid mode-coupling, the multi-mode fiber in Wyatt is "nominally straight" and has a length of at most one meter. (Wyatt, col. 7, l. 1-5 and 57-60). Wyatt states that any imperfections in the fiber can

cause intermode coupling and greatly reduce the length the fundamental mode can travel without coupling to higher order modes. (Wyatt, col. 7, l. 60-66). Thus, a person of ordinary skill would read Wyatt as disclosing, at most, use of very short lengths of very straight multi-mode fiber to avoid coupling optical energy into higher order modes.

Appellant notes that if the proposed modification or combination of the prior art would change the principle of operation of the prior art invention being modified, then the teachings of the references are not sufficient to render the claims *prima facie* obvious. M.P.E.P. 2143.01. The proper inquiry is "whether there is something in the prior art as a whole to suggest the *desirability*, and thus the obviousness, of making the combination." M.P.E.P. 2143.01 (emphasis in original).

Appellant respectfully submits that bending the straight, multi-mode fiber in Wyatt would cause coupling of energy into high order modes and thereby change Wyatt's principle of operation, which is based on propagating the fundamental mode down a multimode fiber "*if the fibre is nominally straight.*" (See, Wyatt, col. 7, lines 3-4, emphasis added). Additionally, Appellant respectfully submits that Wyatt's teaching that multi-mode fiber should be *straight* (e.g., to avoid intermode coupling) would strongly suggest to a person of ordinary skill that *bent* multi-mode fiber is *undesirable*. The Examiner asserts that Wyatt does not teach away from bending fibers, because Wyatt discloses only the undesirability, rather than the *impossibility*, of using bent fibers. Appellant respectfully submits the Examiner's assertion that teaching away requires "impossibility" is contrary to established law, which holds the burden is on the Examiner to show the prior art as a whole suggests the *desirability* of combining the teachings of the references to achieve the claimed invention. See, e.g., *In re Fulton*, 391 F.3d 1195, 1200, 73 U.S.P.Q. 2d 1141, 1145-46 (Fed. Cir. 2004). Therefore, the Examiner is mistaken that Appellant must show the impossibility of combining the references to establish the prior art teaches away from the combination.

Because Wyatt teaches away from bending fiber, Appellant therefore respectfully submits that the Examiner has failed to establish "an apparent reason to combine the known elements in

the fashion claimed by the [application] at issue," and therefore the rejection is improper. See, *KSR,* 550 U.S. __; 127 S.Ct. at 1741.

Appellant respectfully submits the rejection is improper for additional reasons. For example, Fermann III discloses bending a fiber with a *single-mode* core to reduce environmentally-induced nonlinear polarization changes in the fiber. Since the Examiner admits that Wyatt does not disclose bending a *multi-mode* fiber (Office Action mailed September 25, 2006, page 17), the combination of Wyatt and Fermann III, even if appropriate, does not teach or suggest at least a bent multi-mode fiber as recited in Claim 55.

The Examiner further contends that Kim discloses coiling multi-mode fiber to strip light in higher order modes without stripping light in the fundamental mode. Appellant respectfully points out that to the extent Kim teaches or suggests a coiled multi-mode fiber as a mode stripper, the coiled multi-mode fiber is not disposed "within said laser cavity" (see, e.g., Kim, 604 in Fig. 9). The Examiner states that Kim is introduced "as disclosing and motivating stripping of higher order modes." (Final Office Action, page 17). Even assuming that Kim discloses stripping higher order modes, Appellant respectfully submits the Examiner has not established an "apparent reason" why a person of ordinary skill would dispose such a mode stripper "within said laser cavity," which may lead to more complicated laser design and packaging. Moreover, Kim does not teach or suggest that the mode stripper may be used for "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber" as recited in Claim 55. Accordingly, the combination of Wyatt and Kim does not teach or suggest each of the limitations in Claims 55, and the rejection is improper.

Additionally, Kim discloses coiling a single-clad, *double-mode* fiber (Kim, col. 19, line 40) "to strip light propagating in the *second order mode* from the fiber without affecting the light propagating in the first order mode." (Kim, col. 5, lines 36-45, emphasis added). Appellant respectfully submits that one of ordinary skill would recognize that a general multi-mode fiber typically has a much higher level of mode coupling than is present in Kim's double-mode fiber. For example, certain multi-mode fibers usable with the present invention are capable of propagating from 3 to 3000 modes. See, e.g., Claim 64. Therefore, even assuming that it is

appropriate to combine Wyatt's teaching of a straight multi-mode fiber with Kim's teaching of a coiled mode-stripper for second-order modes, the Examiner has not established that the combination provides a reasonable expectation of success for stripping *higher-order* modes, which may number in the thousands. In the Final Office Action, the Examiner simply asserts, without citation to any authority, that "there would be a reasonable expectation of success that modes having order higher than second order would be stripped if the second order mode were stripped." (Page 18). Appellant points out that "[a]ssertions of technical facts in areas of esoteric technology must always be supported by citation to some reference work recognized as standard in the pertinent art." *In re Ahlert*, 424 F.3d 1088, 1091, 165 U.S.P.Q. 418, 420 (C.C.P.A. 1970). Therefore, Appellant respectfully contends that, even to the extent Kim discloses a mode stripper, the Examiner has simply not met the burden to demonstrate that the combination of cited art would teach or "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber." Accordingly, Appellant respectfully submits the rejection is improper for this reason as well.

Claims 57 and 66

Claims 57 and 66 depend from independent Claim 55 and include all the limitations of Claim 55 as well as additional limitations that define the scope of the inventions in these dependent claims. Because, as discussed above, the cited references, singly or in combination, do not teach or suggest all the limitations of Claim 55, the rejection of Claims 57 and 66 is improper in view of their dependency from Claim 55.

Claims 59-61

Claims 59-61 recite a laser including, among other limitations, a length of multi-mode optical fiber that is "bent" (Claim 59) or "coiled" (Claims 60-61). For substantially the same reasons as discussed above for Claim 55, Appellant respectfully submits that the cited combination of art, either alone or in combination, does not teach bent or coiled multimode optical fiber and the rejection is improper.

13. The rejection of Claims 59-61 and 66 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III

Claims 59-61 and 66

Claims 59-61 recite a laser including, among other limitations, a length of multi-mode optical fiber that is "bent" (Claim 59) or "coiled" (Claims 60-61). Claim 66 depends from independent Claim 55 and recites a method wherein, among other limitations, the "bent multi-mode fiber comprises a coil of multi-mode fiber."

The Examiner states that Fermann III discloses coiling fiber onto a drum to achieve efficient absorption of skew rays from the pump and that it would have been obvious to make the multimode fiber (presumably in Wyatt) have a coil. (Final Office Action, page 13). As discussed above in Grounds for Rejection 12, Wyatt strongly teaches away from bending (or coiling) multimode fiber. Therefore, the proposed combination of Wyatt and Fermann III is improper, because it would change the principle of operation of the prior art invention being modified. M.P.E.P. 2143.01. Therefore, Appellant respectfully submits that the Examiner has failed to establish "an apparent reason to combine the known elements in the fashion claimed by the [application] at issue," because the references teach away from making the combination and the combination would change the principle of operation of the device. See, *KSR* 550 U.S. at __; 127 S.Ct. at 1741. Therefore, the rejection is improper.

14. The rejection of Claim 56 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III or Kim, further in view of Fermann III

Claim 56

Claim 56 recites a method as defined in Claim 55 "additionally comprising mode locking said light energy." The Examiner admits that Wyatt in view of Fermann III or Kim does not disclose mode locking light energy as recited in Claim 56. (Office Action mailed September 25, 2006, page 17). The Examiner contends that Fermann III discloses modelocking; however, as discussed above, to the extent Fermann III discloses modelocking, it is in the context of a *single-mode* fiber and not a *multi-mode* fiber as recited in Claim 56. Accordingly, not only does the

combination of references fail to teach or suggest all the claim limitations, a person of ordinary skill would have no motivation to combine these references in order to achieve modelocking in *multi-mode* fibers, which, as of the filing date, was considered to be "impossible." (Application, page 7, line 12). Appellant submits the rejection is improper.

15. The rejection of Claims 10-11 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Cohen

<u>Claims 10-11</u>

Claims 10-11 depend from Claim 1 (through intervening claims) and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above in Ground for Rejection 4, Appellant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1 and claims depending therefrom. The Examiner relies on Cohen for teaching fusion splicing and tapering fibers but has not identified any teaching or suggestion in Cohen that relates to "a pump coupled to said cladding" of a multi-mode optical fiber. Therefore, the combination of Wyatt and Cohen does not teach or suggest all of the limitations of independent Claim 1 or dependent Claims 10-11. Therefore, Appellant respectfully submits the rejection of Claims 10-11 is improper.

16. The rejection of Claims 13-15 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Goldberg

<u>Claims 13-15</u>

Claims 13-15 depend from Claim 1 (through intervening claims) and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above in Ground for Rejection 4,

Appellant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1 and claims depending therefrom. Moreover, as discussed above, Wyatt teaches away from coupling pump light to the cladding. For example, Wyatt describes an example of a cladding-pumped double-clad fiber in which pump light is launched into an elliptical outer cladding of the fiber. (Wyatt, col. 2, lines 3-10). Wyatt describes the arrangement as having "an extremely complex structure, which makes fabrication very difficult." (Wyatt, col. 2, lines 6-7). Performance is "highly dependent on launch conditions" which are described as being "complicated." (Wyatt, col. 2, lines 8-10). To avoid these difficulties, Wyatt pumps light into the high-NA *core* of a multi-mode fiber. (Wyatt, col. 1, lines 59-62 and col. 5, lines 23-25). Thus, Appellant respectfully submits that Wyatt teaches *core*-pumping a fiber in a laser cavity and teaches away from *cladding*-pumping the fiber.

The Examiner cites Goldberg for disclosing v-groove side pumping. Appellant respectfully submits that because Wyatt teaches the benefits of core-pumping and teaches away from cladding pumping (such as, e.g., v-groove side pumping), the proposed combination of Wyatt and Goldberg is improper. Also, the combination of Wyatt and Goldberg would change the principle of operation of the prior art invention being modified (e.g., the core-pumped fiber in Wyatt), . M.P.E.P. 2143.01. Therefore, Appellant respectfully submits that the Examiner has failed to establish "an apparent reason to combine the known elements in the fashion claimed by the [application] at issue," and the rejection is improper. See, *KSR* 550 U.S. at __; 127 S.Ct. at 1741.

17. The rejection of Claim 42 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III, further in view of Harter I or Galvanauskas I

Claim 42

Claim 42 depends from Claim 1 (through intervening claims) and includes all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a "multi-mode optical fiber." As discussed above in Ground for Rejection 3, Fermann III does not

disclose "multi-mode optical fiber." Also, as discussed above in Ground for Rejection 4, Wyatt discloses coupling pump light to a multi-mode fiber *core* but does not teach or suggest "a pump coupled to said cladding." The Examiner relies on Harter and Galvanauskas I for teachings related to an "output coupler" but has not identified teachings in these references related to "a pump coupled to said cladding" of a "multi-mode optical fiber." Appellant therefore respectfully submits that the Examiner has not established a prima facie case that the combination of the cited references teaches or suggests all the limitations of Claim 42. Therefore, Appellant respectfully submits the rejection of Claim 42 is improper.

18. The rejection of Claims 43-45 under 35 U.S.C. § 103(a) as obvious over Wyatt in view of Fermann III further in view of either Harter I or Galvanauskas I, further in view of Arbore and Galvanauskas II

Claims 43-45

Claims 43-45 depend from Claim 1 (through intervening claims) and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a "multi-mode optical fiber." Claims 43-45 also recite "a frequency converter for compressing pulses generated by said cavity." As discussed above in Ground for Rejection 3, Fermann III does not disclose "multi-mode optical fiber." Also, as discussed above in Ground for Rejection 4, Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding." The Examiner relies on the other cited references for teaching periodically poled LiNbO3, frequency doubling ultra-short pulses, and harmonic pulse generation. Appellant therefore respectfully submits that the Examiner has not established a prima facie case that the combination of the cited references teaches or suggests all the limitations of Claims 43-45. Therefore, Appellant respectfully submits the rejection of Claims 43-45 is improper.

19. The statutory double patenting rejection of Claim 65 under 35 U.S.C. § 101 as claiming the same invention as Claim 64

Claim 65

Claims 64 and 65 read as follows (with emphasis added):

> 64. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes <u>between 3 and 3000</u>.
>
> 65. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes <u>between 3 and 1000</u>.

The Examiner rejects Claims 65 under statutory double patenting as claiming the same invention as Claim 64. Appellant respectfully submits that, *on their face*, Claims 64 and 65 do not define the "same invention," because the claimed ranges for the number of propagating modes is *different*. It is well-settled that statutory double patenting requires the "same invention" be claimed twice, and "same invention" means *identical* subject matter. *Miller v. Eagle Mfg. Co.*, 151 U.S. 186, 200 (1894); *In re Vogel*, 422 F.2d 438, 441, 164 U.S.P.Q. 619, 622 (C.C.P.A. 1970). The test for "same invention" double patenting is "whether one of the claims could be literally infringed without literally infringing the other. If it could be, the claims do not define identically the same invention." *Vogel*, 422 F.2d at 441, 164 U.S.P.Q. at 622. Appellant respectfully submits that a laser as defined in Claim 1, wherein the length of multi-mode optical fiber is capable of supporting a number of propagating modes equal to, for example, 2000, would literally infringe Claim 64 but would not literally infringe Claim 65. Therefore, Claims 64 and 65 do not define the "same invention," and the Examiner's rejection is improper.

20. The nonstatutory obviousness-type double patenting rejection of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 as being unpatentable over the claims of Fermann I

Legal Background on Non-Statutory Double Patenting

Appellant respectfully points out that nonstatutory double patenting requires a comparison of earlier *claims* to later *claims* and not a comparison of the *disclosures*. "Because nonstatutory double patenting compares earlier and later claims, an earlier patent's disclosure is not available to show nonstatutory double patenting. Of course, the earlier patent's disclosure may register on the patentability scale if that patent qualifies as prior art under 35 U.S.C. § 102, which is generally not the case." See, *Geneva Pharmaceuticals, Inc. v. GlaxoSmithKline PLC*, 349 F.3d 1373, 1385, 68 U.S.P.Q. 2d 1865, 1875 (Fed. Cir. 2003); see, also, *Vogel*, 422 F.2d at 441, 164 U.S.P.Q. at 622 ("the patent disclosure may not be used as prior art.").

Moreover, in analyzing possible double patenting, claims must be read "as a whole," with every limitation being material. See, *General Foods Corp. v. Studiengesellschaft Kohle mbH,* 972 F.2d 1272, 1278, 1280, 23 U.S.P.Q. 2d 1839, 1845 (Fed. Cir. 1992). "[I]t is important to bear in mind that comparison can be made only with what invention is *claimed* in the earlier patent, paying careful attention to the rules of claim interpretation to determine what invention a claim *defines* and not looking to the claim for anything that happens to be mentioned in it as though it were a prior art reference." *Id.* 972 F.2d at 1280, 23 U.S.P.Q. 2d at 1845 (emphasis in original). There can be no double patenting if the *inventions* defined in the claims are patentably distinct. *Id.* 972 F.2d at 1278, 23 U.S.P.Q. 2d at 1845.

As discussed above in Ground for Rejection 1, Appellant notes that Fermann I is not prior art under 35 U.S.C. § 102, because the claims of the present application derive from the work of Martin E. Fermann, a co-inventor of the Fermann I patent. Applicant submitted two Rule 132 declarations establishing that Martin E. Fermann is the inventor of the two pending independent Claims 1 and 55 (as well as dependent Claims 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50). See, Rule 132 Declaration entered December 21, 2006 (Appendix 1) and Rule 132 Declaration entered January 10, 2006 (Appendix 3). Because Fermann I is not prior art under

Section 102, only the *claims*, and not the *disclosure*, of the Fermann I patent are available for the nonstatutory obviousness-type double patenting analysis.

Claim 1

The Examiner asserts that Claim 25 of Fermann I anticipates Claim 1 of the present application. Appellant respectfully submits that Claim 25 of Fermann I, which is directed to an optical amplification system, defines *a patentably distinct invention* than Claim 1, which is directed to a laser. As discussed above, for the purposes of a double patenting rejection, the Examiner may only compare the *invention* of Claim 25 of Fermann I with the *invention* of Claim 1 of the present application, and cannot use the teachings of these references as prior art. Appellant points out that the Patent Office has classified the claims of Fermann I in class 359 ("Optical: Systems and Elements") and subclass 341, which is for subject matter related to an "Optical Amplifier" wherein "amplification is produced within a glass or plastic filament by the interaction of externally applied energy and a unique property of the filament (e.g., lasing material)." However, the Patent Office has classified the claims of the present application in a *different* class 372 ("Coherent Light Generators") and subclass 6, which is for subject matter relating to an "Optical Fiber Laser" in which "the laser is constructed in the form of an optical fiber." Accordingly, for the purposes of the double patenting rejection, the separate classifications of Claim 25 and Claim 1 show that each *claimed invention* has attained recognition in the art as a separate subject for inventive effort. See, M.P.E.P. 808.02. Appellant respectfully submits that for at least these reasons, the double patenting rejection of Claim 1 is improper.

Appellant further submits that the other claims of Fermann I do not define the same inventions (or an obvious variant) as defined Claim 1 of the present application. For example, Claim 1 recites "a pump coupled to said cladding [of a multi-mode optical fiber] for exciting said gain medium," which is not taught or suggested by the inventions defined by the Fermann I claims. The Examiner simply asserts a "pump is recited, and the pump would couple to the cladding" without providing any evidence for this assertion. For example, pump light may couple to the *core* of a fiber (rather than the cladding), as discussed above in Ground for Rejection 4 in relation to the Wyatt patent

cited by the Examiner. Further, even accepting the Examiner's assertion for the sake of argument, the Examiner has not articulated a reason why this assertion would establish that Claim 25 of Fermann I anticipates (or renders obvious) Claim 1 of the present application. Accordingly, Appellant respectfully submits the rejection of Claim 1 is improper.

<u>Claims 2-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66</u>

The Examiner asserts that Claim 25, "modified (and motivated) by the prior art applied above (under the 102 and 103 rejections), if necessary, renders obvious the remaining claims." Appellant respectfully submits that the Examiner's mere assertion of obviousness, without additional evidence, cannot establish a *prima facie* case of nonstatutory obviousness-type double patenting. See, *In re Kaplan*, 789 F.2d 1574, 1580, 229 U.S.P.Q. 678, 684 (Fed. Cir. 1986) ("there must be some clear evidence to establish why the variation would have been obvious"). Because an obviousness-type double patenting analysis parallels an obviousness rejection under 35 U.S.C. § 103(a), the Examiner must set forth, for *each* rejected claim, the factual inquiries required by the Supreme Court in *Graham v. John Deere*. 383 U.S. 1, 17 (1966). The examination guidelines state the burden is on the examiner to "make clear: (A) [t]he differences between the inventions defined by the conflicting claims - a claim in the patent compared to a claim in the application; and (B) [t]he reasons why a person of ordinary skill in the art would conclude that the invention defined in the claim at issue is anticipated by, or would have been an obvious variation of, the invention defined in a claim in the patent." See, M.P.E.P. 804(II)(B)(1) and 2141. The Examiner's mere assertion that these claims are rendered obvious by Claim 25 of Fermann I combined with the cited art ("if necessary") simply does not meet the Examiner's burden required by the Supreme Court and the Patent Office.

Accordingly, Appellant respectfully contends that the Examiner has not established a prima facie case that any of these claims are anticipated by or rendered obvious over the claims of Fermann I. Therefore, the non-statutory obviousness-type double patenting rejection is improper.

21. The nonstatutory obviousness-type double patenting rejection of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 as being unpatentable over the Claims 1-4 of Fermann IV (U.S. Patent No. 6,275,512)

The present application is a continuation of the application which issued as the Fermann IV patent. Both the application and the patent have the same inventor: Martin E. Fermann. The Fermann IV patent is not Section 102 prior art to the present application and, for reasons similar to those discussed above in Ground for Rejection 20, the disclosure of the Fermann IV patent cannot be used as prior art in the nonstatutory obviousness-type double patenting analysis.

Claim 55

The Examiner asserts that Claim 1 of Fermann IV modified (and motivated) by Fermann I to include a mode filter would render obvious Claim 55 of the present application.

Appellant respectfully notes that Claims 1-4 of Fermann IV (the only claims in the patent) are directed to methods of generating ultra-short *pulses* (with peak power above 1kW), whereas Claim 55 is directed to *continuous wave* (cw) methods. Accordingly, the inventions defined by the claims of Fermann IV and the invention defined by Claim 55 of the present application are patentably distinct, because it is well recognized by persons of ordinary skill that pulsed and continuous wave optical amplification methods are different. Appellant respectfully submits the rejection of Claim 55 is improper.

Appellant further submits that the Examiner's combination of the Fermann IV claims and the Fermann I patent is not appropriate. As discussed above in Ground for Rejection 1, Fermann I discloses a *single-mode* fiber and does not teach or suggest *multi-mode* fibers as recited in the present application's claims. The Examiner has not provided evidence that the combination of the single-mode fiber teachings of Fermann I and the multimode fiber teachings of Fermann IV would give rise to a reasonable expectation of success on the part of a person of ordinary skill. See, *Rinehart*, 531 F.2d at 1053-54, 189 U.S.P.Q. at 148. Moreover, Appellant submits that, even if combined, the combination does not teach or suggest at least all the limitations of Claims 55, such as, for example, "amplifying said light energy within said laser cavity in a bent multi-mode fiber."

The rejection is also improper, because the Examiner simply asserts, without explanation, the claims are obvious in view of the Fermann IV claims and the prior art cited under the Section 102 and 103 rejections. Accordingly, the Examiner has failed to establish a prima facie case of obviousness based on the *Graham v. John Deere* factors and the patent examination guidelines. See, *Graham*, 1 U.S. at 17; and M.P.E.P. 804(II)(B)(1) and 2141.

Claims 56-57 and 66

Claims 56-57 and 66 depend from Claim 55. For similar reasons as discussed above for Claim 55, Claims 56-57 and 66 define continuous wave (cw) methods that are patentably distinct from the methods for generating ultra-short pulses in Fermann IV. Appellant respectfully submits the double patenting rejection is improper. The rejection is also improper, because the Examiner simply asserts, without explanation, the claims are obvious in view of the Fermann IV claims and the prior art cited under the Section 102 and 103 rejections. Accordingly, the Examiner has failed to establish a prima facie case of obviousness based on the *Graham v. John Deere* factors and the patent examination guidelines. See, *Graham*, 1 U.S. at 17; and M.P.E.P. 804(II)(B)(1) and 2141.

Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, and 59-65

These claims define inventions of laser *apparatus* and are patentably distinct from the ultra-short pulse generation *method* inventions defined by the Fermann IV claims, which are in an entirely different statutory class of invention. 35 U.S.C. § 101. For at least this reason, the double patenting rejection based on Fermann IV is improper.

The rejection is also improper, because the Examiner simply asserts, without explanation, that the claims are obvious in view of the Fermann IV claims and the prior art cited under the Section 102 and 103 rejections. Accordingly, the Examiner has failed to establish a prima facie case of obviousness based on the *Graham v. John Deere* factors and the patent examination guidelines. See, *Graham*, 1 U.S. at 17; and M.P.E.P. 804(II)(B)(1) and 2141.

Conclusion

For the reasons set forth above, Appellant respectfully submits that the rejections of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 are improper, and request that these rejections be reversed.

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VIII. CLAIMS APPENDIX

1. A laser, comprising:

a cavity which repeatedly passes light energy along a cavity axis;

a length of multi-mode optical fiber having a cladding and doped with a gain medium and positioned along said cavity axis;

a pump coupled to said cladding for exciting said gain medium; and

an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber.

2. A laser as defined in Claim 1 additionally comprising a mode locking mechanism positioned on said cavity axis, wherein said mode locking mechanism comprises a passive mode locking element.

3. A laser as defined in Claim 2 wherein said passive mode locking element comprises a saturable absorber.

4. A laser as defined in Claim 3 wherein said saturable absorber comprises InGaAsP.

5. A laser as defined in Claim 3 additionally comprising a power limiter for protecting said saturable absorber.

6. A laser as defined in Claim 5 wherein said power limiter comprises a two photon absorber.

7. A laser as defined in Claim 1 wherein said optical guide comprises a single-mode mode-filter fiber on said cavity axis.

8. A laser as defined in Claim 7 wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber.

10. A laser as defined in Claim 8 wherein said single-mode mode-filter fiber is tapered at said fusion splice.

11. A laser as defined in Claim 8 wherein both said single-mode mode-filter fiber and said multi-mode fiber are tapered at said fusion splice.

13. A laser as defined in Claim 1 wherein said pump is coupled to the side of said multi-mode fiber.

14. A laser as defined in Claim 13 additionally comprising an optical coupler for coupling said pump to said multi-mode fiber.

15. A laser as defined in Claim 13 additionally comprising a v-groove on said multi-mode optical fiber for coupling said pump to said multi-mode fiber.

16. A laser as defined in Claim 1 additionally comprising a polarization beam splitter for outputting light from said laser.

17. A laser as defined in Claim 1 wherein said cavity comprises a pair of reflectors at its opposite ends.

18. A laser as defined in Claim 17 wherein one of said pair of reflectors is partially reflecting and provides the output for said cavity.

19. A laser as defined in Claim 17 additionally comprising a mode locking mechanism positioned on said cavity axis, wherein said mode locking mechanism comprises a saturable absorber, and wherein one of said reflectors is formed on a surface of said saturable absorber.

20. A laser as defined in Claim 19 wherein said mode locking mechanism additionally comprises a power limiter for protecting said saturable absorber, and wherein said saturable absorber is formed on a surface of said power limiter opposite said one of said reflectors.

21. A laser as defined in Claim 20 wherein said power limiter comprises a two-photon absorber.

22. A laser as defined in Claim 1 additionally comprising a linear phase drift compensator on said cavity axis.

23. A laser as defined in Claim 22 wherein said linear phase drift compensator comprises a Faraday rotator.

24. A laser as defined in Claim 23 wherein said linear phase drift compensator comprises a pair of Faraday rotators.

25. A laser as defined in Claim 22 additionally comprising a linear polarization transformer on said cavity axis.

26. A laser as defined in Claim 25 wherein said linear polarization transformer comprises a wave plate.

30. A laser as defined in Claim 1 configured to generate ultra-short optical pulses, wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec.

31. A laser as defined in Claim 1 additionally comprising an environmental stabilizer on said cavity axis to assure that said cavity remains environmentally stable.

32. A laser as defined in Claim 31 wherein said environmental stabilizer comprises a Faraday rotator.

33. A laser as defined in Claim 32 wherein said environmental stabilizer comprises a pair of Faraday rotators.

35. A laser as defined in Claim 34 wherein said amplifying medium is concentrated centrally within a fraction of a core diameter of said optical fiber of said optical guide.

36. A laser as defined in Claim 1 wherein said optical guide comprises a single-mode optical fiber on said cavity axis.

37. A laser as defined in Claim 1 wherein said optical guide comprises a mode-filter on said cavity axis.

38. A laser as defined in Claim 37 wherein said mode filter confines said light energy substantially to the fundamental mode of said multi-mode fiber.

39. A laser as defined in Claim 38 wherein said mode filter confines said light energy substantially to the fundamental mode of said multi-mode fiber with an efficiency of at least 90%.

40. A laser as defined in Claim 1 wherein said cavity additionally comprises a positive dispersion element.

41. A laser as defined in Claim 40 wherein said positive dispersion element comprises a length of single-mode positive dispersion fiber positioned along said cavity axis.

42. A laser as defined in Claim 41 additionally comprising an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity.

43. A laser as defined in Claim 42 additionally comprising a frequency converter for compressing pulses generated by said cavity.

44. A laser as defined in Claim 43 wherein said frequency converter comprises a frequency doubler.

45. A laser as defined in Claim 44 wherein said frequency doubler comprises chirped periodically poled $LiNbO_3$.

46. A laser as defined in Claim 1 wherein said multi-mode fiber includes a core, and wherein said gain medium in said multi-mode optical fiber is concentrated centrally within the core of said multi-mode fiber.

50. A laser as defined in Claim 1 wherein said cavity additionally comprises a fiber grating written onto said multi-mode fiber, said grating primarily reflecting the fundamental mode of said multi-mode fiber.

55. A method, comprising:

circulating light energy within a laser cavity;

amplifying said light energy within said laser cavity in a bent multi-mode fiber; and

confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber.

56. A method as defined in Claim 55 additionally comprising mode locking said light energy.

57. A method as defined in Claim 55 wherein said confining comprises mode filtering said light energy.

59. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is bent.

60. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is coiled.

61. A laser as defined in Claim 60, wherein said coiled length has a diameter of about 5 cm or smaller.

62. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber has a V-value greater than about 2.41.

63. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber has a V-value greater than about 2.5.

64. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 3000.

65. A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 1000.

66. A method as defined in Claim 55, wherein said bent multi-mode fiber comprises a coil of multi-mode fiber.

IX. EVIDENCE APPENDIX

1. Rule 132 Declaration, entered December 21, 2006, and attached hereto as **Appendix 1.**
2. Amendment after Non-Final Rejection (the "Office Action Response"), entered December 21, 2006, and attached hereto as **Appendix 2**. The Office Action Response includes Exhibits 1-5, which are fiber optics references that were submitted with the Office Action Response.
3. Rule 132 Declaration, entered January 10, 2006, and attached hereto as **Appendix 3.**

APPENDIX 1

Appl. No. : 09/785,944
Filed : February 16, 2001

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Martin E. Fermann
Appl. No.	:	09/785,944
Filed	:	February 16, 2001
For	:	MODE-LOCKED MULTI-MODE FIBER LASER PULSE SOURCE
Examiner	:	Hrayr A. Sayadian
Group Art Unit	:	2828

DECLARATION UNDER 37 C.F.R. § 1.132 OF MARTIN E. FERMANN AND DONALD J. HARTER

1. The undersigned Martin E. Fermann is the sole inventor of the above-captioned patent application.

2. The undersigned Martin E. Fermann and Donald J. Harter are the two named inventors of U. S. Patent No. 5,818,630.

3. The inventions defined by Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 of the above-captioned patent application are the sole invention of Martin E. Fermann.

4. To the extent that the inventions defined by Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 of the above-captioned patent application are disclosed in U. S. Patent 5,818,630, the inventions were derived from Martin E. Fermann.

5. We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like

so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of the application or any patent issued thereon.

Respectfully submitted,

Dated: 12.20.2006

By: ______________
Martin E. Fermann

Dated: 12/20/06

By: ______________
Donald J. Harter

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121406

APPENDIX 2

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Fermann, Martin E.
Appl. No.	:	09/785,944
Filed	:	February 16, 2001
For	:	Mode-Locked Multi-Mode Fiber Laser Pulse Source
Examiner	:	Hrayr A. Sayadian
Group Art Unit	:	2828
Confirmation No.	:	7227

RESPONSE TO SEPTEMBER 25, 2006 OFFICE ACTION

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This paper is submitted in response to the Office Action mailed September 25, 2006 in the above-captioned application.

Amendments to the Specification begin on page 2 of this paper.

Amendments to the Claims are reflected in the listing of claims which begins on page 3 of this paper.

Summary of Interview begins on page 9 of this paper. Exhibits 1-5 are attached.

Remarks begin on page 11 of this paper.

A **Declaration under 37 C.F.R. § 1.132** is attached hereto.

AMENDMENTS TO THE SPECIFICATION

Applicant amends the first paragraph of the section entitled "DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT" (paragraph [0047] as published) as indicated below.

[0047] FIG. 1A illustrates the mode-locked laser cavity 11 of this invention which uses a length of multi-mode amplifying fiber 13 within the cavity to produce ultra-short, high-power optical pulses. As used herein, "ultra-short" means a pulse width below 100 ps. The fiber 13, in the example shown, is a 1.0 m length of non-birefringent Yb^{3+}/Er^{3+}-doped multi-mode fiber. Typically, a fiber is considered multi-mode when the V-value exceeds 2.41, i.e., when modes in addition to the fundamental mode can propagate in the optical fiber. <u>In particular, V-values higher than 2.5 and relatively high index differences between core and cladding (i.e. a Δn>0.3%) can be effectively employed. Further, the number of modes is preferably in the range of 3 to 3000 and more preferably in the range of 3 to 1000.</u> This fiber is coiled onto a drum with a diameter of 5 cm, though bend diameters as small as 1.5 cm, or even smaller, may be used without inhibiting mode-locking. Due to the Er^{3+} doping, the fiber core in this example has an absorption of approximately 40 dB/m at a wavelength of 1.53 μm. The Yb^{3+} co-doping produces an average absorption of 4.3 dB/m inside the cladding at a wavelength of 980 nm. The fiber 13 has a numerical aperture of 0.20 and a core diameter of 16 μm. The outside diameter of the cladding of the fiber 13 is 200 μm. The fiber 13 is coated with a low-index polymer producing a numerical aperture of 0.40 for the cladding. A 10 cm length of single-mode Corning Leaf fiber 15 is thermally tapered to produce a core diameter of approximately 14 μm to ensure an optimum operation as a mode filter, and this length is fusion spliced onto a first end 17 of the multi-mode fiber 13.

AMENDMENTS TO THE CLAIMS

Claims 2, 16, 19, 30, 35, 38, and 39 are amended herein. Claims 9, 12, 27-29, 47-49, and 58 are withdrawn without prejudice or disclaimer. Claim 34 is canceled without prejudice or disclaimer. New claims 59-66 are added.

1. (Previously Presented) A laser, comprising:

a cavity which repeatedly passes light energy along a cavity axis;

a length of multi-mode optical fiber having a cladding and doped with a gain medium and positioned along said cavity axis;

a pump coupled to said cladding for exciting said gain medium; and

an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber.

2. (Currently Amended) A laser as defined in Claim 1 <u>additionally comprising a mode locking mechanism positioned on said cavity axis,</u> wherein said mode locking mechanism comprises a passive mode locking element.

3. (Previously Presented) A laser as defined in Claim 2 wherein said passive mode locking element comprises a saturable absorber.

4. (Previously Presented) A laser as defined in Claim 3 wherein said saturable absorber comprises InGaAsP.

5. (Previously Presented) A laser as defined in Claim 3 additionally comprising a power limiter for protecting said saturable absorber.

6. (Previously Presented) A laser as defined in Claim 5 wherein said power limiter comprises a two photon absorber.

7. (Previously Presented) A laser as defined in Claim 1 wherein said optical guide comprises a single-mode mode-filter fiber on said cavity axis.

8. (Previously Presented) A laser as defined in Claim 7 wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber.

9. (Withdrawn) A laser as defined in Claim 8 wherein said multi-mode fiber is tapered at said fusion splice.

10. (Previously Presented) A laser as defined in Claim 8 wherein said single-mode mode-filter fiber is tapered at said fusion splice.

11. (Previously Presented) A laser as defined in Claim 8 wherein both said single-mode mode-filter fiber and said multi-mode fiber are tapered at said fusion splice.

12. (Withdrawn) A laser as defined in Claim 1 wherein said pump is coupled to said multi-mode fiber along said cavity axis.

13. (Previously Presented) A laser as defined in Claim 1 wherein said pump is coupled to the side of said multi-mode fiber.

14. (Previously Presented) A laser as defined in Claim 13 additionally comprising an optical coupler for coupling said pump to said multi-mode fiber.

15. (Previously Presented) A laser as defined in Claim 13 additionally comprising a v-groove on said multi-mode optical fiber for coupling said pump to said multi-mode fiber.

16. (Currently Amended) A laser as defined in Claim 1 additionally comprising a polarization beam splitter for outputting ~~said ultra-short optical pulses~~ light from said laser.

17. (Previously Presented) A laser as defined in Claim 1 wherein said cavity comprises a pair of reflectors at its opposite ends.

18. (Previously Presented) A laser as defined in Claim 17 wherein one of said pair of reflectors is partially reflecting and provides the output for said cavity.

19. (Currently Amended) A laser as defined in Claim 17 additionally comprising a mode locking mechanism positioned on said cavity axis, wherein said mode locking mechanism comprises a saturable absorber, and wherein one of said reflectors is formed on a surface of said saturable absorber.

20. (Previously Presented) A laser as defined in Claim 19 wherein said mode locking mechanism additionally comprises a power limiter for protecting said saturable absorber, and wherein said saturable absorber is formed on a surface of said power limiter opposite said one of said reflectors.

21. (Previously Presented) A laser as defined in Claim 20 wherein said power limiter comprises a two-photon absorber.

22. (Previously Presented) A laser as defined in Claim 1 additionally comprising a linear phase drift compensator on said cavity axis.

23. (Previously Presented) A laser as defined in Claim 22 wherein said linear phase drift compensator comprises a Faraday rotator.

24. (Previously Presented) A laser as defined in Claim 23 wherein said linear phase drift compensator comprises a pair of Faraday rotators.

25. (Previously Presented) A laser as defined in Claim 22 additionally comprising a linear polarization transformer on said cavity axis.

26. (Previously Presented) A laser as defined in Claim 25 wherein said linear polarization transformer comprises a wave plate.

27. (Withdrawn) A laser as defined in Claim 1 wherein said mode locking mechanism comprises an active mode locking element.

28. (Withdrawn) A laser as defined in Claim 27 wherein said active mode locking element comprises an optical amplitude modulator.

29. (Withdrawn) A laser as defined in Claim 27 wherein said active mode locking element comprises an optical frequency modulator.

30. (Currently Amended) A laser as defined in Claim 1 configured to generate ultra-short optical pulses, wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec.

31. (Previously Presented) A laser as defined in Claim 1 additionally comprising an environmental stabilizer on said cavity axis to assure that said cavity remains environmentally stable.

32. (Previously Presented) A laser as defined in Claim 31 wherein said environmental stabilizer comprises a Faraday rotator.

33. (Previously Presented) A laser as defined in Claim 32 wherein said environmental stabilizer comprises a pair of Faraday rotators.

34. (Canceled)

35. (Currently Amended) A laser as defined in Claim 34 wherein said amplifying medium is concentrated centrally within a fraction of [[the]] a core diameter of said optical fiber of said optical guide.

36. (Previously Presented) A laser as defined in Claim 1 wherein said optical guide comprises a single-mode optical fiber on said cavity axis.

37. (Previously Presented) A laser as defined in Claim 1 wherein said optical guide comprises a mode-filter on said cavity axis.

38. (Currently Amended) A laser as defined in Claim 37 wherein said mode filter ~~excites~~ confines said light energy substantially to the fundamental mode of said multi-mode fiber.

39. (Currently Amended) A laser as defined in Claim 38 wherein said mode filter ~~excites~~ confines said light energy substantially to the fundamental mode of said multi-mode fiber with an efficiency of at least 90%.

40. (Previously Presented) A laser as defined in Claim 1 wherein said cavity additionally comprises a positive dispersion element.

41. (Previously Presented) A laser as defined in Claim 40 wherein said positive dispersion element comprises a length of single-mode positive dispersion fiber positioned along said cavity axis.

42. (Previously Presented) A laser as defined in Claim 41 additionally comprising an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity.

43. (Previously Presented) A laser as defined in Claim 42 additionally comprising a frequency converter for compressing pulses generated by said cavity.

44. (Previously Presented) A laser as defined in Claim 43 wherein said frequency converter comprises a frequency doubler.

45. (Previously Presented) A laser as defined in Claim 44 wherein said frequency doubler comprises chirped periodically poled $LiNbO_3$.

46. (Previously Presented) A laser as defined in Claim 1 wherein said multi-mode fiber includes a core, and wherein said gain medium in said multi-mode optical fiber is concentrated centrally within the core of said multi-mode fiber.

47. (Withdrawn) A laser as defined in Claim 1 wherein said multi-mode optical fiber is polarization-maintaining.

48. (Withdrawn) A laser as defined in Claim 47 wherein said polarization-maintaining multi-mode fiber has an elliptical core.

49. (Withdrawn) A laser as defined in Claim 47 wherein said polarization maintaining multi-mode fiber comprises stress-producing regions.

50. (Previously Presented) A laser as defined in Claim 1 wherein said cavity additionally comprises a fiber grating written onto said multi-mode fiber, said grating primarily reflecting the fundamental mode of said multi-mode fiber.

51 – 54. (Canceled)

55. (Previously Presented) A method, comprising:

circulating light energy within a laser cavity;

amplifying said light energy within said laser cavity in a bent multi-mode fiber; and

confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber.

56. (Previously Presented) A method as defined in Claim 55 additionally comprising mode locking said light energy.

57. (Previously Presented) A method as defined in Claim 55 wherein said confining comprises mode filtering said light energy.

58. (Withdrawn) A mode-locked laser, comprising:

A multi-mode optical fiber doped with gain material for amplifying optical energy;

a source for pumping said optical fiber; and

a tapered length of multi-mode fiber for confining the optical energy amplified by said multi-mode optical fiber to substantially the fundamental mode of said multi-mode optical fiber.

59. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is bent.

60. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is coiled.

61. (New) A laser as defined in Claim 60, wherein said coiled length has a diameter of about 5 cm or smaller.

62. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber has a V-value greater than about 2.41.

63. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber has a V-value greater than about 2.5.

64. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 3000.

65. (New) A laser as defined in Claim 1, wherein said length of multi-mode optical fiber is capable of supporting a number of propagating modes between 3 and 1000.

66. (New) A method as defined in Claim 55, wherein said bent multi-mode fiber comprises a coil of multi-mode fiber.

SUMMARY OF INTERVIEW

An interview was conducted with Examiner Sayadian on November 29, 2006. Attorney James Bear and Dr. Donald Harter, Director of Technology Acquisition, IMRA America, Inc., the assignee of the present application, attended.

Exhibits and/or Demonstrations

The following publications were brought to the interview, and the listed pages were shown to the Examiner.

Handbook of Optics, Optical Society of America, Second Edition Volume II, Pages 10.4, 10.6 and 10.10, copies attached as Exhibit 1.

Optical Waveguide Theory, Allan W. Snyder and John D. Love, 1983, Pages 26, 27, 316, 317, 320, 321, copies attached as Exhibit 2.

Tools of the Trade, ThorLabs, Inc., Volume 17, Page 831, copies attached as Exhibit 3.

Fiber Optic Communications, Joseph C. Palais, Prentice Hall, Fourth Edition, Pages 102, 103, 104, 105, 116, 117, 118, 119, copies attached as Exhibit 4.

Theory of Dielectric Optical Waveguides, Second Edition, Dietrich Marcuse, Academic Press, Inc., Pages 62, 63, 70, 71, copies attached as Exhibit 5.

Identification of Claims Discussed

Independent Claims 1 and 55

Identification of Prior Art Discussed

Fermann I, US 5,627,848; Wyatt, US 5,422,897; and Kim, US 4,832,437

Proposed Amendments

None

Principal Arguments and Other Matters

Applicant's representatives used the publications attached to this summary to argue that, in the ordinary usage of the terms "single mode" and "multi-mode" as used in the claims of the application, the mode or modes being referred to are core modes, not cladding modes. Applicants agreed to make this clear in their response to the most recent office action.

Applicant's representatives also argued that Fermann I (5,627,848) teaches a single mode amplifying fiber, rather than a multi-mode fiber; that Kim (5,422,897) fails to teach bending in an amplifying fiber, and that Wyatt (5,422,897) teaches against the use of a bent or coiled fiber.

Results of Interview

Applicants agreed to present their arguments in an amendment responding to the latest office action.

REMARKS

Claims 1-50 and 55-58 were pending in the application. In response to the Examiner's Election Requirement of April 28, 2006, Applicant elected Claims 1-8, 10, 11, 13-26, 30-46, 50, and 55-57. Accordingly, Applicant withdraws Claims 9, 12, 27-29, 47-49, and 58 from examination without prejudice or disclaimer. Claim 34 is canceled without prejudice or disclaimer. New Claims 59-66 are added. After entry of this amendment, Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, 55-57, and 59-66 will be pending for examination.

In the Office Action dated September 25, 2006 the Examiner rejected Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, and 55-57. Applicant respectfully requests the rejection of these Claims be reconsidered in light of the foregoing amendments and the following remarks.

The rejections will be discussed in the order raised by the Examiner.

35 U.S.C. § 112 REJECTIONS

The Examiner rejected Claims 2-6, 16, 19-21, 30, 35, 38, and 39 as being indefinite. Claims 2 and 19 are amended to clarify the antecedent basis in Claims 2-6 and 19-21 for recitations of "said mode locking mechanism." Claim 16 is amended to recite that the laser outputs "light." Claim 30 is amended to clarify the antecedent basis for "said ultra-short optical pulses." Claim 35 is amended to correct a typographical error and to clarify the antecedent basis for "said optical fiber." Claims 38 and 39 are amended to clarify functioning of the mode filter. Support for these amendments is at least found in the original Claims as filed. These amendments do not narrow the scope of any of the Claims.

Applicant respectfully requests the Examiner to withdraw the Section 112 rejections of Claims 2-6, 16, 19-21, 30, 35, 38, and 39.

35 U.S.C. § 102 REJECTIONS

A. Fermann I

Claims 1-4, 7, 16-19, 22-26, 30-41, 50, and 55-57 are rejected as anticipated by US Patent No. 5,627,848 (Fermann I). Applicant respectfully traverses these rejections.

Claim 1 recites a laser comprising, among other limitations, "a length of multi-mode optical fiber having a cladding and doped with a gain medium and positioned along said cavity

axis." The Examiner asserts that "multi-mode optical fibers" include "fibers that guide multi-modes, whether through the core *or within the cladding*" (emphasis added). Applicant respectfully disagrees with the Examiner's assertion that a multi-mode fiber includes a fiber with cladding-guided multi-modes. As will be discussed further below, at least because Fermann I does not teach a *multi-mode optical fiber* having a cladding and doped with a gain medium, Applicant respectfully submits that the Examiner's rejections are improper.

Single- and Multi-Mode Optical Fibers

Applicant notes that pursuant to M.P.E.P. § 2111.01, the terms of a claim are to be given their "plain meaning," which is "the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention, *i.e.*, as of the effective filing date of the patent application." See *Phillips v. AWH Corp.*, 415 F.3d 1303, 1313 (Fed. Cir. 2005) (*en banc*).

Applicant respectfully submits that when read in the context of the specification and claims a person of ordinary skill would understand a multi-mode optical fiber to refer to an optical fiber comprising a *core* that can support propagation of modes in addition to the fundamental mode. The specification teaches that "a fiber is considered multi-mode when the V-value exceeds 2.41." See, paragraph [0047]. As is well known in the art, the V-value (or normalized frequency) depends on the size of the fiber *core* (e.g., its radius *a*) relative to the wavelength of light λ propagating in the core.

The Federal Standard FS-1037C (Telecommunications: Glossary of Telecommunication Terms), which the Examiner cites on pages 11-12 to show definitions of terms in the technological arts, provides the following definition of "normalized frequency (V)" (emphasis added):

> **normalized frequency (V): 1.** In an optical fiber, a dimensionless quantity, V, given by
>
> $$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \ ,$$
>
> where a is the core radius, λ is the wavelength in vacuum, n_1 is the maximum refractive index of the core, and n_2 is the refractive index of the homogeneous cladding. *Note 1:* In multimode operation of an optical fiber having a power-law refractive index profile, the approximate number of bound modes, *i.e.*, the mode volume, is given by

$$\frac{V^2}{2}\left(\frac{g}{g+2}\right),$$

> where V is the normalized frequency greater than 5 and g is the profile parameter. *Note 2:* For a step index fiber, the mode volume is given by $V^2/2$. For single-mode operation, $V < 2.405$. Synonym V number.

Applicant respectfully points out that the teaching of the specification that multi-mode operation occurs for a V-value *greater* than 2.41 is consistent with the above definition of single-mode operation for V *less* than 2.405 (see, Note 2 above). Therefore, the FS-1037C standard shows that single-mode and multi-mode fibers are distinguished by light propagation properties of the fiber *core* and not light propagation within the fiber *cladding* as asserted by the Examiner.

The FS-1037C standard provides further support that fiber *core modes*, and not cladding modes, are used to distinguish single- and multi-mode fibers. As indicated in Notes 1 and 2 of the above definition, the V-number is related to the number of "bound modes" in the fiber, which the FS-1037C standard defines as follows:

> **bound mode:** In an optical fiber, a mode that (a) has a field intensity that decays monotonically in the transverse direction everywhere external to the <u>core</u> and (b) does not lose power to radiation. *Note:* Except for single-mode fibers, the power in bound modes is predominantly contained in the <u>core</u> of the fiber. *Synonyms* guided mode, trapped mode. (emphasis added)

Accordingly, bound modes represent propagating modes in the fiber *core,* and the number of such modes may be used to distinguish single-mode and multi-mode fibers. The number of propagating core modes can be determined from the V-number. Applicant respectfully submits that the FS-1037C standards clearly show that a person of ordinary skill would understand that a "multi-mode fiber" is characterized by the number of propagating *core* modes and *not* by the number of cladding modes (which the FS-1037C standard states are "undesired").

The Examiner cites U.S. Patent No. 4,829,529 (Kafka) to support his assertion regarding the scope of the recitation of "multi-mode fiber." Applicant respectfully disagrees with the Examiner's characterization of Kafka. The fiber disclosed in Kafka (see, e.g., Figs. 1,2, and 4) is known in the art as a doubly-clad (or double-clad) fiber defined by the FS-1037C standard as a "single-mode fiber that has two claddings."

Additionally, as discussed by Applicant's representatives during the interview, the Exhibits presented (copies attached) establish that well-known fiber optic reference sources characterize single- and multi-mode fibers by the properties of propagating *core* modes, not cladding modes. Moreover, the Exhibits further establish that single- and multi-mode fibers can be defined by the V-value of the *core* of the fiber. See, e.g., Exhibit 1, p. 10.10; Exhibit 2, p. 317; and Exhibit 4, p. 116-118.

In summary, Applicant respectfully submits that the plain meaning of the term "multi-mode optical fiber," as used in the specification and claims, is a fiber comprising a <u>core</u> capable of propagating optical modes in addition to the fundamental mode. A fiber is considered multi-mode if $V > 2.405$, with V determined by core properties (e.g., core radius).

Fermann I discloses a double-clad optical fiber comprising a <u>single-mode core</u>. The core properties described in column 4, l. 20-40 result in a V-value of about 2, which is well-below the upper limit (2.405) of the single-mode regime. Accordingly, Fermann I discloses a <u>single-mode fiber</u> and does not teach or suggest multi-mode fibers as used in the specification and claims.

<u>Independent Claim 1</u>

Claim 1 recites a laser comprising, among other limitations, "a length of *multi-mode optical fiber*" and "an optical guide positioned on said cavity axis which confines the light amplified by said *multi-mode optical fiber* to preferentially the fundamental mode of said *multi-mode optical fiber*." As discussed above, Fermann I does not disclose a multi-mode optical fiber in a laser.

Applicant respectfully requests the Examiner to withdraw the rejection of Claim 1 as anticipated by Fermann I.

<u>Independent Claim 55</u>

Claim 55 recites a method comprising, among other limitations, amplifying "light energy within said laser cavity in a bent *multi-mode fiber*" and "confining said light energy within said laser cavity substantially to the fundamental mode of said *multi-mode fiber*." As discussed above, Fermann I does not disclose methods using multi-mode optical fiber.

For at least this reason, Applicant respectfully requests the Examiner to withdraw the rejection of Claim 55 as anticipated by Fermann I.

Dependent Claims

Claims 2-4, 7, 16-19, 22-26, 30-33, 35-41, 50 depend from Claim 1 and Claims 56-57 depend from Claim 55. The dependent claims include all the limitations of the base independent claims, respectively, as well as additional limitations that define the scope of the inventions in these dependent claims. Because Fermann I does not disclose all the limitations of independent Claims 1 and 55, Applicant respectfully submits that the rejection of the claims depending from the independent claims is improper. For at least this reason, Applicant respectfully requests withdrawal of the rejection of Claims 2-4, 7, 16-19, 22-26, 30-33, 35-41, 50, 56-57 as anticipated by Fermann I.

B. Wyatt

Claims 1, 7, 8, 17, 18, 35-39, 46, and 50 are rejected as anticipated by US Patent No. 5,422,897 (Wyatt). Applicant respectfully traverses these rejections.

Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. Wyatt does not disclose pump light coupled to the cladding. In Wyatt, the pump light is coupled to the multi-mode *core* of a single-clad fiber. See, e.g., col. 1, l. 56-62; and col. 4, l. 52-64. For example, Wyatt teaches that the numerical aperture (NA) of the multimode fiber core should large, e.g., by having "as high a value of Δn [refractive index difference between core and cladding] as possible to enable optimum coupling of light from the pump source into the multimode fiber." See, col. 1, l. 59-62 and col. 5, l. 23-25. It is well known in the art that a large NA permits greater coupling of optical energy into the *core* of a single-clad fiber.

Wyatt also describes the use of a computer generated hologram (CGH) as an optical coupling means for coupling the pump power into the multimode fiber. See, col. 6, l. 2-5. The CGH is used to convert the output of the pump (e.g., a laser diode array) "to a focused spot." See, col. 1, l. 53-55. Such a focused spot provides good optical coupling to the core of the fiber.

Moreover, Wyatt teaches away from coupling pump light to the cladding. For example, Wyatt describes an example of a cladding-pumped double-clad fiber in which pump light is launched into an elliptical outer core of the fiber. See, col. 2, l. 3-10. Wyatt describes the arrangement as having "an extremely complex structure, which makes fabrication very difficult." See, col. 2, l. 6-7. Performance is "highly dependent on launch conditions" which are described

as being "complicated." See, col. 2, l. 8-10. To avoid these difficulties, Wyatt pumps light into the high-NA *core* of a multi-mode fiber. See, col. 1, l. 59-62 and col. 5, l. 23-25.

Accordingly, Applicant respectfully submits that Wyatt discloses pump light coupled to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1. For at least this reason, Wyatt does not teach or suggest all the limitations of Claim 1; therefore, the anticipation rejection of Claim 1 is improper.

Also, for at least this reason, the rejections of Claims 7, 8, 17, 18, 35-39, 46, and 50, which depend from Claim 1 and include further limitations, are improper. Applicant respectfully requests withdrawal of the anticipation rejections based on Wyatt.

C. Fermann II

Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 are rejected under 35 U.S.C. §§ 102(a) and 102(e) as being anticipated by U.S. Patent No. 5,818,630 (Fermann II). Applicant respectfully traverses these rejections.

The inventors of the Fermann II patent are Martin E. Fermann and Donald J. Harter. The inventor of the claims of the present application is Martin E. Fermann. Attached to this amendment is a declaration by Martin E. Fermann and Donald J. Harter, pursuant to 37 C.F.R. § 1.132, that establishes, to the extent the inventions of Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 are disclosed in U.S. Patent No. 5,818,630, the inventions in these claims were not patented "before the invention thereof by the applicant for patent" as required by 35 U.S.C. § 102(a) and were not "by another" as required under 35 U.S.C. § 102(e). See, also, M.P.E.P. 706.02(b).

Accordingly, based on the attached declaration, Applicant overcomes the Examiner's rejection of these claims and requests withdrawal of the rejection based on Fermann II.

<u>35 U.S.C. § 103 REJECTIONS</u>

Applicant notes that to establish a prima facie case of obviousness, three basic criteria must be met:

> First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or

references when combined) must teach or suggest all the claim limitations. M.P.E.P. 2143.

Applicant respectfully submits that the cited references, either alone or in any combination, do not, at least, teach or suggest all the limitations of rejected Claims 2-6, 8-11, 13-16, 19-26, 30-33, 40-45, and 55-57. Applicant also respectfully submits that the Examiner has not identified a suggestion or motivation for combining the references or that there is a reasonable expectation of success. For at least theses reasons, Applicant traverses the Examiner's Section 103 rejections.

A. Fermann I

Claims 5, 6, 8-11, 13-15, 20, 21, and 42-45 are rejected as being unpatentable over Fermann I either alone or in various combinations with other cited art. These claims depend from and include all the limitations of Claim 1, which recites, among other limitations, "a length of multi-mode optical fiber" and "an optical guide positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber to preferentially the fundamental mode of said multi-mode optical fiber."

As discussed further above, Applicant respectfully submits that Fermann I discloses only a single-mode fiber and does not teach or suggest at least the limitations of Claim 1 (and its dependent claims) reciting multi-mode fiber. In the Section 103 rejections, the Examiner relies on Fermann I or the other cited references for teaching or suggesting additional limitations of the claims, but *not* as teaching or suggesting use of multi-mode fiber as recited in the claims. Accordingly, Applicant respectfully submits the Examiner's obviousness rejections are improper at least because the various combinations of cited references do not teach or suggest all the claim limitations. The claim rejections will be discussed further below.

<u>Claims 5, 6, 20, and 21</u>

These claims stand rejected over Fermann I alone. Since, as previously discussed, Fermann I does not teach or suggest multi-mode fiber as recited in these claims, Applicant respectfully requests these rejections be withdrawn.

<u>Claims 8-11, 13-15, and 42-45</u>

Applicant respectfully submits the Examiner has not established a *prima facie* obviousness rejection of Claims 8-11, 13-15, and 42-45 at least because the Examiner has not

identified any teaching or suggestion in any of the cited references (alone or in combination) for multi-mode optical fiber as recited in these claims. Accordingly, Fermann I and the other references (alone or in combination) do not teach or suggest all the claim limitations, and Applicant respectfully requests withdrawal of the rejections of these claims.

Additionally, Applicant respectfully disagrees with the Examiner's contentions that the cited references teach or suggest various other claim limitations. For example, the Examiner cites U.S. Patent No. 5,074,633 (Cohen) for teaching fusion splice tapered connection of fibers. Applicant notes that Cohen describes a fusion splice between two single-clad fibers, which are "typically single-mode fibers." Col. 4, l. 20-21. Cohen does not teach or suggest, for example, fiber connections where "said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber" as recited in Claims 8-11. Also, the Examiner cites the Goldberg reference for teaching v-groove side pumping. However, Goldberg teaches forming a v-groove on a fiber having a single-mode core (see, p. 208) and not "a v-groove on said multi-mode optical fiber for coupling said pump to said multi-mode fiber."

B. Wyatt

Claims 2-6, 9-11, 13-16, 19-26, 30-33, 40-45, and 55-57 are rejected as being unpatentable over Wyatt in combination with other cited references. Applicant respectfully traverses these rejections.

<u>Claims 2-6, 9-11, 13-16, 19-26, 30-33, and 40-45</u>

These claims depend from and include all the limitations of Claim 1 as well as other limitations which further define the scope of the inventions in these claims. Claim 1 recites, among other limitations, "a pump coupled to said cladding" of a multi-mode optical fiber. As discussed above, Applicant respectfully submits that Wyatt discloses coupling pump light to a multi-mode fiber *core* and does not teach or suggest "a pump coupled to said cladding" as recited in Claim 1.

Applicant respectfully submits the Examiner has not established a *prima facie* obviousness rejection of Claims 2-6, 9-11, 13-16, 19-26, 30-33, and 40-45 at least because the Examiner has not identified any teaching or suggestion in any of the cited references (alone or in combination) for a pump coupled to the cladding of a multi-mode optical fiber as recited in these claims. Accordingly, Wyatt and the other references (alone or in combination) do not teach or

suggest all the claim limitations, and Applicant respectfully requests withdrawal of the rejections of these claims.

Additionally, Applicant respectfully disagrees with the appropriateness of the Examiner's combination of the cited references. As noted above, there must be a suggestion or motivation to combine the references as well as a reasonable expectation of success.

For example, regarding Claims 2-6, 19-21, and 30, the Examiner cites the combination of Wyatt, Fermann I, and an article to DeSouza. Applicant agrees with the Examiner that Wyatt does not teach or suggest modelocking. However, Applicant respectfully submits that the Examiner has not established a suggestion or motivation to combine the references, or that, even if combined, there would be a reasonable expectation of success. For example, to the extent that Fermann I and DeSouza disclose modelocking, it is in the context of *single-mode* fibers and not *multi-mode* fibers as recited in this application's claims. The present application teaches that the stability of modelocked depends critically on minimizing spurious reflections in the oscillator, which are conceptually equivalent to mode-coupling in multi-mode fibers. See, paragraphs [0030]-[0031]. The application also teaches that mode-coupling of higher order modes in a multi-mode fiber also suppresses mode-locking. Id.; see, also, Fermann I, col. 5, l. 38-60. In fact, as of the filing date of the application, modelocking of a multi-mode fiber was considered "impossible." See, paragraph [0031].

Accordingly, Applicant respectfully submits that the Examiner has not identified why a person of ordinary skill would be motivated to combine any possible teachings of Fermann I and DeSouza regarding modelocking in a single-mode fiber to the more difficult problem of modelocking in a multi-mode fiber. Additionally and for the sake of argument only, even if the references are combined, the Examiner has not demonstrated that any combined teachings relevant to modelocking in single-mode fibers will provide a reasonable expectation of success for modelocking in multi-mode fibers.

<u>Claims 55-57</u>

The Examiner rejects Claims 55-57 based on Wyatt in view of Fermann I or Kim (U.S. Patent No. 4,832,437). Independent Claim 55 is a method including, among other limitations, "amplifying said light energy within said laser cavity in a bent multi-mode fiber." The Examiner admits that Wyatt does not disclose bending the multi-mode fiber. Applicant respectfully

submits that Wyatt strongly teaches away from bending multi-mode fiber, because bent multi-mode fiber causes "significant coupling of power into higher order modes." Col. 7, l. 4-5 and 57-60. Such mode coupling makes it "difficult to control the amount of optical energy that exists in any single mode at any given time." Col. 6, l. 67-68. To avoid mode-coupling, the multi-mode fiber in Wyatt is "nominally straight" and has a length of at most one meter. Col. 7, l. 1-5 and 57-60. Wyatt states that any imperfections in the fiber can cause intermode coupling and greatly reduce the length the fundamental mode can travel without coupling to higher order modes. Col. 7, l. 60-66. Thus, a person of ordinary skill would read Wyatt as disclosing, at most, use of very short lengths of very straight multi-mode fiber to avoid coupling optical energy into higher order modes.

Applicant notes that if the proposed modification or combination of the prior art would (i) change the principle of operation of the prior art invention being modified or (ii) would render the prior art invention being modified unsatisfactory for its intended purpose, then the teachings of the references are not sufficient to render the claims *prima facie* obvious. M.P.E.P. 2143.01. The proper inquiry is "whether there is something in the prior art as a whole to suggest the *desirability*, and thus the obviousness, of making the combination." M.P.E.P. 2143.01 (emphasis in original).

Applicant respectfully submits that bending the straight, multi-mode fiber in Wyatt would cause coupling of energy into high order modes and thereby change Wyatt's principle of operation and intended purpose to enable stimulated emission "in *only* the fundamental mode." See, Wyatt Abstract (emphasis added). Additionally, Wyatt's teaching that multi-mode fiber should be straight (e.g., to avoid intermode coupling) strongly suggests that *bent* multi-mode fiber is undesirable. Accordingly, a person of ordinary skill would not be motivated to combine the teachings of Wyatt with *any* references (including, e.g., Fermann I and/or Kim) teaching or suggesting bending the optical fiber. Therefore, for at least this reason, Applicant respectfully submits that the Examiner has not established a *prima facie* case of obviousness for independent Claim 55.

Applicant notes that if "an independent claim is nonobvious under 35 U.S.C. 103, then any claim depending therefrom is nonobvious." M.P.E.P. 2143.03, citing *In re Fine*, 837 F.2d 1071, 1076 (Fed. Cir. 1988). Accordingly, Applicant respectfully submits that for at least this

reason the obviousness rejections of Claims 56 and 57, which depend from independent Claim 55, are improper.

Additionally, Applicant respectfully disagrees with the appropriateness of the Examiner's combination of the cited references. For example, Fermann I discloses bending a fiber with a *single-mode* core to reduce environmentally-induced nonlinear polarization changes in the fiber. Since the Examiner admits that Wyatt does not disclose bending a *multi-mode* fiber, the combination of Wyatt and Fermann I, even if appropriate, does not teach or suggest at least a bent multi-mode fiber as recited in Claims 55-57.

The Examiner further contends that Kim discloses coiling multi-mode fiber to strip light in higher order modes without stripping light in the fundamental mode. Applicant respectfully points out that to the extent Kim teaches or suggests a coiled multi-mode fiber as a mode stripper, the coiled multi-mode fiber is not disposed "within said laser cavity" (see, e.g., Fig. 9). Also, Kim does not teach or suggest that the mode stripper may be used for "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber" as recited in Claims 55-57. Accordingly, the combination of Wyatt and Kim does not teach or suggest each of the limitations in Claims 55-57.

Moreover, Applicant points out that rather than disclosing apparatus or methods usable with a laser or a laser cavity, Kim discloses an inter-propagation mode frequency shifter for an optical signal in a fiber. See, e.g., Abstract; Summary of the Invention, col. 2, l. 28-34; col. 5, l. 20-26; l. 52-57. Kim's disclosure does not relate to laser but rather to devices such as fiber optic gyros. See, col. 1, l. 25. Applicant respectfully submits that the Examiner has not identified a suggestion or motivation why a person of ordinary skill would combine Wyatt's teaching on lasers with Kim's teachings on frequency shifters for gyros or, even if combined, why there would be a reasonable expectation of success.

Additionally, Kim discloses coiling a single-clad, *double-mode* fiber (col. 19, l. 40) "to strip light propagating in the *second order mode* from the fiber without affecting the light propagating in the first order mode." Col. 5, l. 36-45 (emphasis added). Applicant respectfully submits that one of ordinary skill would recognize that a general multi-mode fiber typically has a much higher level of mode coupling than is present in Kim's double-mode fiber. For example, certain multi-mode fibers usable with the present invention are capable of propagating from 3 to

3000 modes. See, present application, paragraph [0047] as amended; Fermann II, col. 7, l. 12-14. Therefore, even assuming that it is appropriate to combine Wyatt's teaching of a straight multi-mode fiber with Kim's teaching of a coiled mode-stripper for second-order modes, the Examiner has not established that the combination provides a reasonable expectation of success for stripping *higher-order* modes, which may number in the thousands. Thus, the proposed combination of Wyatt and Kim at least does not teach or suggest "confining said light energy within said laser cavity substantially to the fundamental mode of said multi-mode fiber." Accordingly, Applicant respectfully submits the combination of Wyatt and Kim is improper.

The Examiner admits that Wyatt in view of Fermann I or Kim does not disclose mode locking light energy as recited in Claim 56. The Examiner contends that Fermann I discloses modelocking; however, as discussed above, to the extent Fermann I discloses modelocking, it is in the context of *single-mode* fibers and not *multi-mode* fibers as recited in Claim 56. Accordingly, not only does the combination of references fail to teach or suggest all the claim limitations, a person of ordinary skill would have no motivation to combine these references in order to achieve modelocking in *multi-mode* fibers, which, as of the filing date, was considered to be "impossible" as discussed above.

DOUBLE PATENTING

The Examiner has rejected Claims 1-8, 10, 11, 13-26, 30-33, 35-46, 50, and 55-57 on the ground of nonstatutory obviousness-type double patenting with respect to the Fermann II patent (U.S. Pat. No. 5,818,630) and the Fermann III patent (U.S. Pat. No. 6,275,512). Applicant respectfully disagrees that any of the claims of the present application are anticipated by, or would have been obvious over, the claims of either the Fermann II or Fermann III patents.

Applicant notes that nonstatutory double patenting requires a comparison of earlier *claims* to later *claims* and not a comparison of the *disclosures*. "Because nonstatutory double patenting compares earlier and later claims, an earlier patent's disclosure is not available to show nonstatutory double patenting. Of course, the earlier patent's disclosure may register on the patentability scale if that patent qualifies as prior art under 35 U.S.C. § 102, which is generally not the case." See, *Geneva Pharmaceuticals, Inc. v. GlaxoSmithKline PLC*, 349 F.3d 1373,

1385 (Fed. Cir. 2003); see, also, *In re Vogel*, 422 F.2d 438, 441 (CCPA 1970) ("the patent disclosure may not be used as prior art.).

Moreover, in analyzing possible double patenting, claims must be read "as a whole," with every limitation being material. See, *General Foods Corp. v. Studiengesellschaft Kohle mbH,* 972 F.2d 1272, 1278, 1280 (Fed. Cir. 1992). "[I]t is important to bear in mind that comparison can be made only with what invention is *claimed* in the earlier patent, paying careful attention to the rules of claim interpretation to determine what invention a claim *defines* and not looking to the claim for anything that happens to be mentioned in it as though it were a prior art reference." *Id.* at 1280 (emphasis in original). There can be no double patenting if the *inventions* defined in the claims are patentably distinct. *Id.* at 1278.

Fermann II

As discussed above, Applicant notes that Fermann II is not prior art under 35 U.S.C. § 102, because the claims of the present application derive from the work of Martin E. Fermann, a co-inventor of the Fermann II patent (see attached 1.132 declaration). Therefore, only the claims, and not the disclosure, of the Fermann II patent are available for the nonstatutory obviousness-type double patenting analysis.

The Examiner asserts that Claim 25 of Fermann II anticipates Claim 1 of the present application. Applicant respectfully submits that Claim 25, which is directed to an optical amplification system, defines *a different invention* than Claim 1, which is directed to a laser. For at least this reason, the double patenting rejection is improper. Additionally, Applicant notes that Claim 25 does not disclose all the limitations of Claim 1, such as, for example, "a cavity which repeatedly passes light energy along a cavity axis." Accordingly, Claim 25 of Fermann II does not anticipate Claim 1 of the present application.

Applicant further submits that the other claims of Fermann II do not define the same inventions (or an obvious variant) as defined in the claims of the present application. For example, Claim 1 recites "a pump coupled to said cladding [of a multi-mode fiber] for exciting said gain medium," which is not taught or suggested by the inventions defined by the Fermann II claims.

The Examiner asserts that Claim 25, "modified (and motivated) by the prior art applied above (under the 102 and 103 rejections), if necessary, renders obvious the remaining claims." Applicant respectfully submits that the Examiner's mere assertion of obviousness, without

additional evidence, cannot establish a *prima facie* case of nonstatutory obviousness-type double patenting. See, *In re Kaplan,* 789 F.2d 1574, 1580 (Fed. Cir. 1986) ("there must be some clear evidence to establish why the variation would have been obvious").

Accordingly, Applicant respectfully contends that the Examiner has not shown that the claims of the present application are anticipated by or rendered obvious over the claims of Fermann II. Applicant respectfully submits that the claims of the present application define inventions that are patentably distinct from the inventions defined in the Fermann II claims and respectfully requests the Examiner to withdraw the double patenting rejection based on the Fermann II patent.

<u>Fermann III</u>

The present application is a continuation of the application which issued as the Fermann III patent. Both the application and the patent have the same inventor: Martin E. Fermann. Therefore, the Fermann III patent is not Section 102 prior art to the present application and, for reasons similar to those discussed above for Fermann II, the disclosure of the Fermann III patent cannot be used as prior art in the nonstatutory obviousness-type double patenting analysis.

The Examiner asserts that Claim 1 of Fermann III modified (and motivated) by Fermann I to include a mode filter would render obvious Claim 55 of the present application. The Examiner also asserts that the other application claims would be obvious in view of the cited art (without providing any evidence or analysis).

Applicant respectfully notes that Claims 1-4 of Fermann III (the only claims in the patent) are directed to methods of generating ultra-short *pulses* (with peak power above 1kW), whereas Claims 55-57 are directed to *continuous wave* (cw) methods. Accordingly, the inventions defined by the claims of Fermann III and the present application are patentably distinct, because it is well recognized by persons of ordinary skill that pulsed and continuous wave optical amplification methods are substantially different. Additionally, Applicant submits that the double patenting rejections of Claims 1-8, 10, 11, 13-26, 30-33, 35-46, and 50 of the present application are improper. These claims define inventions of laser *apparatus* and are clearly patentably distinct from the ultra-short pulse generation *method* inventions defined by the

Fermann III claim, which are in an entirely different statutory class of invention. For at least these reasons, the double patenting rejection based on Fermann III is improper.

Applicant further submits that the combination of the Fermann III claims and the Fermann I patent is not appropriate. As discussed above, Fermann I discloses a single-mode fiber and does not teach or suggest multi-mode fibers as recited in the present application's claims. The Examiner has not identified a suggestion or motivation to combine these references or that the combination would give rise to a reasonable expectation of success. Moreover, Applicant submits that, even if combined, the combination does not teach or suggest at least all the limitations of Claims 55-57, such as, for example, "amplifying said light energy within said laser cavity in a bent multi-mode fiber."

Accordingly, Applicant respectfully contends that the Examiner has not shown that the claims of the present application are anticipated by or rendered obvious over the claims of Fermann III in view of the cited art. Applicant respectfully submits that the claims of the present application define inventions that are patentably distinct from the inventions defined in the Fermann III claims and respectfully requests the Examiner to withdraw the double patenting rejection based on the Fermann III patent.

AMENDMENT TO THE SPECIFICATION

Applicant amends the first paragraph of the section entitled "DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT" (paragraph [0047] as published) as indicated herein. The added material relates to the V-value and number of propagating modes in multi-mode fiber and is taken verbatim from U.S. Patent No. 5,818,630 (Fermann II), which is incorporated by reference in paragraph [0009] of the present application. The material added from Fermann II includes one sentence from col. 3, l. 12-15 and one sentence from col. 7, l. 12-14. No new matter is added by this amendment.

NEW CLAIMS

New claims 59-66 are added herein. Support for these claims is found at least in paragraph [0047] as amended herein. No new matter is added.

SUMMARY

Accordingly, Applicant respectfully submits that all of the pending claims are in condition for allowance and requests the present application be passed to issue.

By making the foregoing amendments and remarks and by focusing on specific claims and claim limitations in the discussion above, Applicant does not imply agreement with the positions set forth in the Office Action regarding other claims or claim limitations or the teachings of the cited art. Applicant also does not imply agreement with the positions in the Office Action that various combinations of the cited art are suggested or motivated by the prior art, have a reasonable expectation of success, or teach or suggest all the claim limitations.

Please charge any additional fees, including any fees for additional extension of time, or credit overpayment to Deposit Account No. 11-1410.

Respectfully submitted,

KNOBBE, MARTENS, OLSON & BEAR, LLP

Dated: 12/21/2006

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Attachments: Exhibits 1-5
Declaration under 37 C.F.R. § 1.132 of Martin E. Fermann and Donald J. Harter

Appl. No. : 09/785,944
Filed : February 16, 2001

EXHIBIT 1

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II

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published several books on fiber optics. The interested reader is referred to the "Further Reading" section at the end of this chapter for additional reference material.

Optical fiber science and technology relies heavily on both geometrical and physical optics, materials science, integrated and guided-wave optics, quantum optics and optical physics, communications engineering, and other disciplines. Interested readers are referred to other chapters within this collection for additional information on many of these topics.

The applications which are discussed in detail in this chapter are limited to information technology and telecommunications. Readers should, however, be aware of the tremendous activity and range of applications for optical fibers in metrology and medicine. The latter, which includes surgery, endoscopy, and sensing, is an area of tremendous technological importance and great recent interest. While the fiber design may be quite different when optimized for these applications, the general principles of operation remain much the same. A list of references which are entirely devoted to optical fibers in medicine is listed in "Further Reading".

10.3 PRINCIPLES OF OPERATION

The optical fiber falls into a subset (albeit the most commercially significant subset) of structures known as dielectric optical waveguides. The general principles of optical waveguides are discussed elsewhere in Chap. 6 of Vol. II, "Integrated Optics"; the optical fiber works on principles similar to other waveguides, with the important inclusion of a cylindrical axis of symmetry. For some specific applications, the fiber may deviate slightly from this symmetry; it is nevertheless fundamental to fiber design and fabrication. Figure 1 shows the generic optical fiber design, with a core of high refractive index surrounded by a low-index cladding. This index difference requires that light from inside the fiber which is incident at an angle greater than the critical angle

$$\theta_c = \sin^{-1}\left(\frac{n_1}{n_0}\right) \tag{1}$$

be totally internally reflected at the interface. A simple geometrical picture appears to allow a continuous range of internally reflected rays inside the structure; in fact, the light (being a wave) must satisfy a self-interference condition in order to be trapped in the waveguide. There are only a finite number of paths which satisfy this condition; these are analogous to the propagating electromagnetic modes of the structure. Fibers which support a large number of modes (these are fibers of large core and large numerical aperture) can be adequately analyzed by the tools of geometrical optics; fibers which support a small

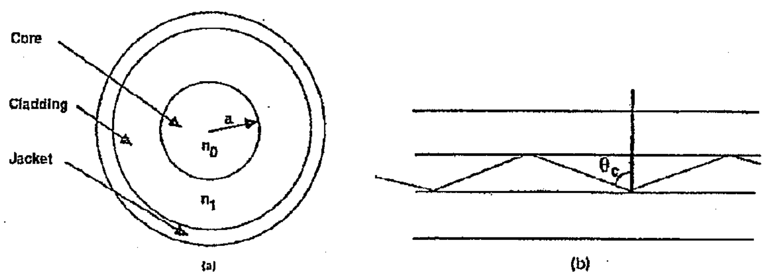

FIGURE 1 (a) Generic optical fiber design, (b) path of a ray propagating at the geometric angle for total internal reflection.

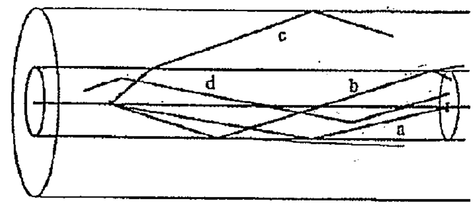

FIGURE 4 Classification of geometrical ray paths in an optical fiber. (*a*) Meridional ray; (*b*) leaky ray; (*c*) ray corresponding to a cladding mode; (*d*) skew ray.

laser-fiber coupling. A larger core and larger numerical aperture will, in general, yield a higher coupling efficiency. Coupling between fibers which are mismatched either in core or numerical aperture is difficult and generally results in excess loss.

The final concept for which a geometrical construction is helpful is ray classification. Those geometrical paths which pass through the axis of symmetry and obey the self-interference condition are known as *meridional rays*. There are classes of rays which are nearly totally internally reflected and may still propagate some distance down the fiber. These are known as *leaky rays* (or modes). Other geometrical paths are not at all confined in the core, but internally reflect off of the cladding-air (or jacket) interface. These are known as *cladding modes*. Finally, there exists a class of geometrical paths which are bound, can be introduced outside of the normal numerical aperture of the fiber, and do not pass through the axis of symmetry. These are often called *skew rays*. Figure 4 illustrates the classification of geometrical paths.

Geometrical optics has a limited function in the description of optical fibers, and the actual propagation characteristics must be understood in the context of guided-wave optics. For waveguides such as optical fibers which exhibit a small change in refractive index at the boundaries, the electric field can be well described by a scalar wave equation,

$$\nabla^2\Psi(r,\theta,z) + k_0^2 r^2(r)\Psi(r,\theta,z) = 0 \tag{2}$$

the solutions of which are the modes of the fiber. $\Psi(r, \theta, z)$ is generally assumed to be separable in the variables of the cylindrical coordinate system of the fiber:

$$\Psi(r,\theta,z) = R(r)\Theta(\theta)Z(z) \tag{3}$$

This separation results in the following eigenvalue equation for the radial part of the scalar field:

$$\frac{d^2R}{dr^2} + \frac{1}{r}\frac{dR}{dr} + \left(k_0^2 n^2(r) - \beta^2 - \frac{m^2}{r^2}\right)R = 0 \tag{4}$$

in which m denotes the azimuthal mode number, and β is the propagation constant. The solutions must obey the necessary continuity conditions at the core-cladding boundary. In addition, guided modes must decay to zero outside the core region. These solutions are readily found for fibers having uniform, cylindrically symmetric regions but require numerical methods for fibers lacking cylindrical symmetry or having an arbitrary index gradient. A common form of the latter is the so-called *α-profile* in which the refractive index exhibits the radial gradient[4]

$$m(r) = \begin{cases} n_1\left[1 - \Delta\left(\frac{r}{a}\right)^{\alpha}\right] & r < a \\ n_1[1-\Delta] = n_2 & r \geq a \end{cases} \tag{5}$$

TABLE 1 Normalized Variables in the Mathematical Description of Optical Fibers

Symbol	Description
$k_0 = \frac{2\pi}{\lambda}$	Vacuum wave vector
a	Core radius
n_0	Core index
n_1	Cladding index
$\bar{\beta} = \beta' + i\beta''$	Mode propagation constant
$\alpha = 2\beta''$	Fiber attenuation
$N_{\text{eff}} = \beta'/k_0$	Effective index of mode
$\Delta = \frac{n_0^2 - n_1^2}{2n_1^2}$	Normalized core-cladding index differences
$V = \sqrt{2k_0}\, an_1\Delta$	Normalized frequency
$b = \left(\frac{N_{\text{eff}}}{n_1} - 1\right)\Big/\Delta$	Normalized effective index
$f(r)$	Gradient-index shape factor
$\Gamma = \dfrac{\int_0^a f(r)\Psi'^2(r)r\,dr}{\int_0^a \Psi^2(r)r\,dr}$	Profile parameter ($\Gamma = 1$ for step-index)

of 1.3 to 1.55 μm. Shorter wavelengths will typically support two or more modes, resulting in significant intermodal interference at the output. In order to guarantee single-mode performance, it is important to determine the single-mode cut-off wavelength for a given fiber. Normalized variables allow one to readily determine the cut-off wavelength and dispersion limits of a fiber using universal curves.

The normalized variables are listed in Table 1 along with the usual designations for fiber parameters. The definitions here apply to the limit of the "weakly guiding" fiber of Gloge,[7] for which $\Delta \ll 1$. The cutoff for single-mode performance appears at a normalized frequency of $V = 2.405$. For values of V greater than this, the fiber is multimode. The practical range of frequencies for good single-mode fiber operation lie in the range

$$1.8 < V < 2.4 \tag{11}$$

An analytic approximation for the normalized propagation constant b which is valid for this range is given by

$$b(V) \approx \left(1 - 1.1428 - \frac{0.996}{V}\right)^2 \tag{12}$$

Operation close to the cutoff $V = 2.405$ risks introducing higher-order modes if the fiber parameters are not precisely targeted. A useful expression which applies to step-index fibers relates the core diameter and wavelength at the single-mode cutoff[5]:

$$\lambda_{\text{cutoff}} = \left(\frac{\pi}{2.405}\right)(2a)n_0\sqrt{2\Delta} \tag{13}$$

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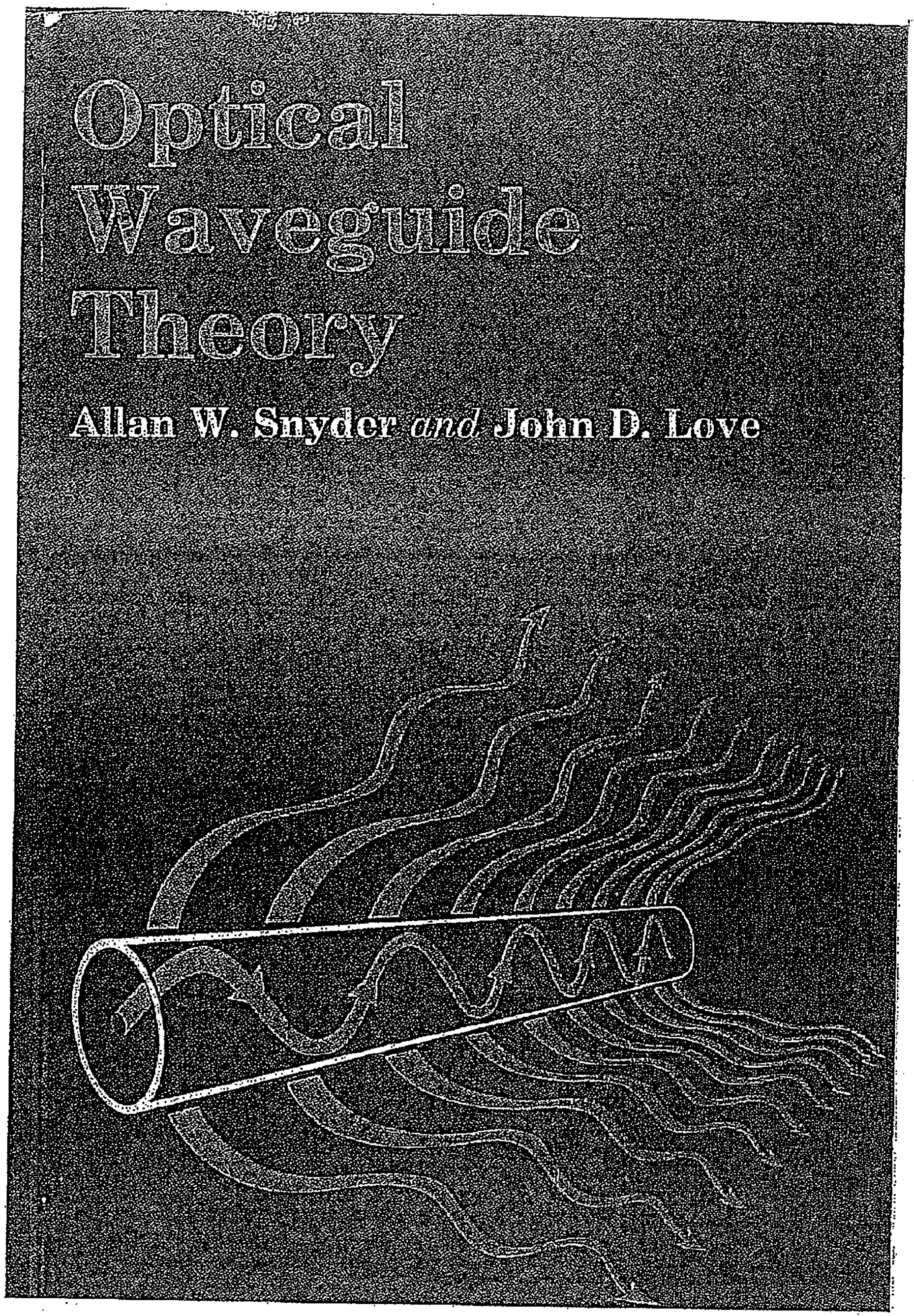
Filed : **February 16, 2001**

EXHIBIT 2



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CHAPTER 2

Bound rays of fibers

In Chapter 1 we established the basic concepts for the ray analysis of planar waveguides. Here we extend the analysis to optical fibers, which are used for high-capacity communication over long distances. As far as ray tracing is concerned, the only difference between fibers and planar waveguides is the introduction of the third dimension. Thus, although the ray concepts are the same as in Chapter 1, the analysis and resulting expressions are generally more complicated because of the fiber geometry. Nevertheless, one of the important results of this chapter shows that the ray transit times for step and clad power-law profile fibers of both circular and noncircular cross-sections are identical to

those of the corresponding planar waveguides. If this remarkable simplification is acceptable without proof, then pulse spreading in such fibers can be studied directly by proceeding to Chapter 3 and omitting this chapter at a first reading.

Most of the chapter is devoted to the construction of ray paths and their classification on circular fibers with axisymmetric profiles. However, we also consider noncircular fibers since cross-sections can differ from circular symmetry in practice, e.g. elliptical fibers. Finally, since this chapter parallels Chapter 1 to a large extent, it may be helpful to compare the results of corresponding sections.

2-1 Circular fibers

An optical fiber is illustrated in Fig. 2-1. Unless otherwise stated, the *core* is assumed to have a circularly symmetric cross-section of radius ρ, surrounded by the *cladding*, which, for simplicity, is assumed unbounded. The *core–cladding interface* is the cylindrical surface $r = \rho$. Over the core, the axisymmetric refractive-index profile $n(r)$ is either uniform or graded, and it takes the uniform value n_{cl} in the cladding.

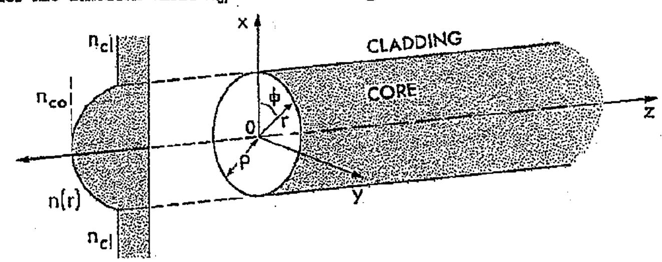

Fig. 2-1 Nomenclature for describing circular fibers. Cartesian coordinates x, y, z and cylindrical polar coordinates r, ϕ, z are oriented so that the z-axis lies along the fiber axis. A representative graded profile varies over the core and is uniform over the cladding, assumed unbounded.

The dimensionless parameter V of Eq. (1-1) also applies to fibers, and will be referred to as the *fiber parameter*. Thus

$$\boxed{V = \frac{2\pi\rho}{\lambda}(n_{co}^2 - n_{cl}^2)^{1/2},} \qquad (2\text{-}1)$$

where n_{co} is the maximum value of $n(r)$, ρ the core radius, and λ the free-space wavelength of light. The quantity $(n_{co}^2 - n_{cl}^2)^{1/2}$ is often referred to as the *numerical aperture* of the fiber, while a related expression $\{n^2(r) - n_{cl}^2\}^{1/2}$ is

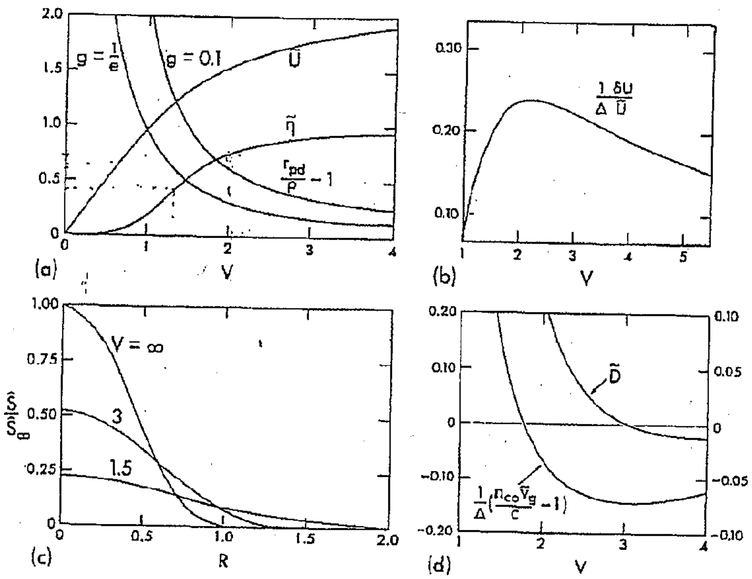

Fig. 14–3 Fundamental mode quantities for the step-profile fiber, showing (a) the modal parameter $\tilde{U}$, the fraction of power in the core $\tilde{\eta}$, and the depth of penetration r_{pd}, (b) the normalized polarization correction $\delta U/\Delta\tilde{U}$, (c) the normalized intensity distribution and (d) the normalized variation in group velocity relative to the left ordinate, and the distortion parameter $\tilde{D}$ relative to the right ordinate. Numerical values are given in Table 14–4.

Depth of penetration of the field intensity

The fundamental-mode intensity in Fig. 14–3(c) can be significant well into the cladding. At sufficiently large distances from the axis it decreases exponentially with R, as is clear from Table 14–3 and Eq. (37–88). To quantify the size of this region, we define r_{pd} to be the distance from the fiber axis where S has fallen to a factor $g < 1$ of its value at the interface. Thus

$$K_0^2\,(\tilde{W}r_{pd}/\rho) = gK_0^2(\tilde{W}). \qquad (14\text{–}18)$$

The normalized distance $(r_{pd}/\rho) - 1$ from the interface is a measure of the effective depth of penetration of the core field into the cladding. We plot this quantity as a function of V in Fig. 14–3(a), taking $g = e^{-1}$ for the lower curve and $g = 0.1$ for the upper curve. For example, when $V = 2.5$ we deduce from the $\tilde{\eta}$ curve that about 84% of total fundamental-mode power flows within the

core, and the intensity, or power density, falls by a factor of e^{-1} over a distance of approximately $\rho/2$ beyond the interface.

Pulse propagation and spreading

If V is below the cutoff value 2.405 of the second mode in Fig. 14–4, the fiber is single moded and only the even and odd fundamental modes can propagate. Both modes have the same propagation constant $\tilde{\beta}$. Consequently the group velocity $\tilde{v}_g$ and the transit time of Eq. (11–36) are independent of polarization. In the weak-guidance approximation, the expression for $\tilde{v}_g$ in Table 14–3 follows from Eq. (13–17), and is plotted against V in Fig. 14–3(d) as the dimensionless quantity $(n_{co}\tilde{v}_g - c)/c\Delta$.

Pulse spreading on single-mode fibers depends only on waveguide dispersion and material dispersion, as discussed in Section 11–12. The contribution to pulse spreading in the absence of material dispersion is proportional to the dimensionless distortion parameter introduced in Section 11–20. Using the definition $\tilde{D}$ for weakly guiding fibers in Table 13–2, page 292, we are led to the expression in Table 14–3. Numerical values of D are given in Table 14–4 and are plotted in Fig. 14–3(d). There is zero waveguide dispersion at $V \cong 3$, which corresponds to the minimum group velocity value.

Approximate forms for large and small values of V

It is often useful to have approximations to the fundamental-mode properties in Table 14–3 when V is either large or small. These approximations are given in Table 14–5. The expressions for the modal parameters are the $\Delta \to 0$ limit of the expression in Table 12–4, page 253, where we have used the small argument expression of J_ν in Eq. (37–82). The remaining expressions in Table 14–5 are obtained from Table 14–3 by using the expansions of K_0 and K_1 in Eqs. (37–86) and (37–88) for small and large arguments, and assuming $\tilde{U} \cong V$ if V is small or $\tilde{W} \cong V$ if V is large. The accuracy of each approximation can be gauged by comparison with the exact values in Table 14–4 for $V = 1.05$ or $V = 4$. For intermediate values of V, an excellent approximation can be derived by assuming $\tilde{W}$ is a linear function of V. This leads to [5].

$$\tilde{W} = 1.1428\,V - 0.996, \quad 1.5 \leqslant V \leqslant 2.5, \qquad (14\text{–}19)$$

which is within 0.2% of the exact values over the range. However, derivatives of this expression do not usually lead to expressions for group velocity and the distortion parameter with the same accuracy [6].

14–7 Higher-order ($l \geqslant 1$) modes

The construction of the remaining modes of the fiber was described in Section 14–3. We give the solution F_l of Eq. (14–4) and the functions $G_l^{\pm}$ in Table 14–6

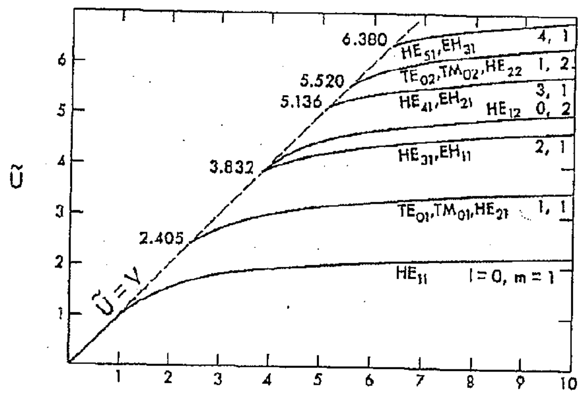

Fig. 14–4 Numerical solutions of the eigenvalue equation of Table 14–6, showing the mode labelling and the corresponding values of l and m. The values along the dashed line are the cutoff values V_c for each mode.

Mode cutoff

With the exception of the fundamental HE_{11} mode, every mode is cut off below a certain value of V and cannot propagate, as explained in Section 11–18. The cutoff value of $\tilde{U}$ is the eigenvalue equation solution in the limit $\tilde{W} \to 0$. With the help of Eq. (37–86), we deduce that $J_{l-1}(\tilde{U}) = 0$ for all modes, including the HE_{1m} modes ($m > 1$) for which $J_1(\tilde{U}) = 0$. This leads to the cutoff values in Fig. 14–4, from which we find that the fiber is single-moded if $V < 2.405$, where $\tilde{U} = V \cong 2.405$ is the cutoff value of the $l = m = 1$ modes. When $\tilde{W} \cong \tilde{V} \to \infty$, we find from the eigenvalue equation and Eq. (37–88) that $\tilde{U}$ satisfies $J_l(\tilde{U}) = 0$. It is readily verified that these limiting equations are the weak-guidance limit of the expressions in Table 12–4, page 253.

Polarization corrections

The corrections $\delta\beta_i$ to the scalar propagation constant are given in Table 14–1 in terms of I_1 and I_2. In the numerator of each expression, the derivative df/dR is the Dirac delta function $\delta(R-1)$, as explained in Section 14–6, and the integral in the denominator is given in Table 14–6. This leads to the expressions for $\delta\beta_i$ and the corresponding δU_i in the same table. There is no correction for the TE_{0m} modes, whose fields satisfy the scalar wave equation exactly.

We plot the ratio $\delta U/\Delta\tilde{U}$ in Fig. 14–5(a) for the TM_{01} mode, which has a maximum value of approximately 0.22 when $V \cong 5$. If we compare the

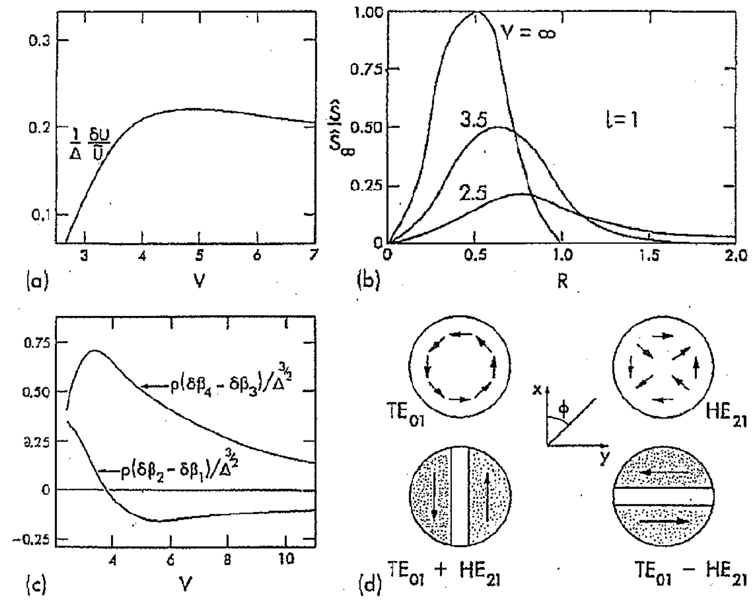

Fig. 14–5 Plots of $l = 1$ mode quantities for the step-profile fiber, showing (a) the normalized vector correction $\delta U/\Delta\tilde{U}$ for the TM_{01} mode, (b) the normalized intensity distribution, (c) the difference in vector corrections for the two pairs of $l = 1$ modes and (d) qualitative representation of the transverse electric field direction, denoted by arrows.

corrected mode parameter $\tilde{U} + \delta U$ with the exact value of U of the TM mode eigenvalue equation in Table 12–4, page 253, the maximum relative error is less than 0.005% for $\Delta = 0.005$ and rises to 0.05% and 0.41% for $\Delta = 0.045$ and $\Delta = 0.125$, respectively.

Interference between modes

The finite propagation constant corrections $\delta\beta_i$ discussed above are responsible for interference effects between pairs of modes with the same scalar propagation constant. For example, suppose the odd HE_{21} and TE_{01} modes are excited with equal power and all other modes have zero power. If we erroneously ignore all polarization effects, then $\delta\beta_3 = \delta\beta_4 = 0$, and the total transverse electric field of the fiber follows from Table 14–1 as

$$\mathbf{E}_t = a\mathbf{e}_{13}\exp(i\tilde{\beta}z) + a\mathbf{e}_{14}\exp(i\tilde{\beta}z) = 2aF_l\sin\phi\,\exp(i\tilde{\beta}z)\hat{\mathbf{x}}, \qquad (14\text{–}20)$$

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EXHIBIT 3

TOOLS OF THE TRADE

THORLABS INC

VOLUME 17

WWW.THORLABS.COM

Highly Doped Ytterbium Fibers

The Yb2000 family of very highly doped ytterbium fibers is designed for those applications where extremely short fiber application length must, such as advanced pulsed applications or applications where non-linear effects must be minimized. These fibers, fabricated using Liekki's Direct Nanoparticle Deposition (DND) technology, seek to maximize the doping density without sacrificing useability.

Yb2000-4/125

Liekki Yb2000-4/125 is a very highly doped ytterbium fiber for low noise, low non-linearity preamplifiers and lasers. Its telecom like geometry makes the fiber compatible with low cost pump diodes and standard single mode passive fibers.

Optical Characteristics:
- Peak absorption at 976nm: 2000 ± 200dB/m
- Peak absorption at 920nm: 600 ± 60dB/m
- Mode field diameter at 1060nm: 4.4 ± 0.8μm
- Core numerical aperture: 0.2 ± 0.02
- Fiber cutoff wavelength: < 920nm

Geometrical Characteristics:
- MDF concentricity error: < 0.7μm
- Cladding diameter: 125 ± 2μm
- Coating diameter: 245 ± 15μm

Yb2000-6/125DC

Liekki Yb2000-6/125DC is a very highly doped ytterbium double clad fiber for low cost single mode lasers and preamplifiers in the 1...10W output power range. Its telecom like geometry makes the fiber compatible with low cost pump diodes and standard single mode passive fibers.

Optical Characteristics:
- Cladding absorption at 976nm (nominal): 5 dB/m
- Cladding absorption at 920nm: 1.5 ± 0.5dB/m
- Mode field diameter at 1060nm: 6.7 ± 0.8μm
- Core numerical aperture: 0.12 ± 0.02

Geometrical Characteristics:
- Cladding diameter: 125 ± 2μm
- Cladding numerical aperture: > 0.46
- Coating diameter: 245 ± 15μm
- Coating material: low index polymer

Yb2000-30/400DC

Yb2000-30/400DC is very highly doped large mode area double clad fiber for high power fiber applications. High absorption makes this fiber ideally suited for pulsed applications, as fiber application lengths can be dramatically shortened. This fiber has high power tolerance and good beam quality.

Optical Characteristics:
- Cladding absorption at 976nm (nominal): 10 dB/m
- Cladding absorption at 920nm: 3 ± 0.5dB/m
- Core numerical aperture: 0.07 ± 0.01

Geometrical Characteristics:
- Core diameter: 30 ± 3μm
- Cladding diameter: 400 ± 15μm
- Cladding numerical aperture: > 0.46
- Coating diameter: 500 ± 15μm
- Coating material: low index polymer

Single mode Yb doped fiber specifications

ITEM	ABSORPTION @976nm	ABSORPTION @920nm	MFD @1060nm	NA CORE	CLADDING DIAMETER	COATING DIAMETER	NA CLADDING
Yb1200-4/125	1200 ± 200dB/m	300 ± 50dB/m	4.4 ± 0.8μm	0.2 ± 0.02	125 ± 2μm	245 ± 15μm	N/A
Yb2000-4/125	2000 ± 200dB/m	600 ± 60dB/m	4.4 ± 0.8μm	0.2 ± 0.02	125 ± 2μm	245 ± 15μm	N/A
Yb2000-6/125DC	5 dB/m (nominal)	1.5 ± 0.5dB/m	6.7 ± 0.8μm	0.12 ± 0.02	125 ± 2μm	245 ± 15μm	>0.46
Yb1200-10/125DC	7dB/m (nominal))	1.7 ± 0.5dB/m	10.5 ± 1μm	0.08 ± 0.01	125 ± 2μm	245 ± 15μm	>0.46

Multimode Yb doped fiber specifications

ITEM	ABSORPTION @976nm	ABSORPTION @920nm	CORE DIAMETER	NA CORE	CLADDING DIAMETER	COATING DIAMETER	NA CLADDING
Yb1200-20/400DC	3dB/m (nominal)	0.7 ± 0.2dB/m	20 ± 2μm	0.07 ± 0.01	400 ± 15μm	500 ± 15μm	>0.46
Yb1200-30/250DC	17dB/m (nominal)	4 ± 1dB/m	30 ± 3μm	0.07 ± 0.01	250 ± 15μm	350 ± 15μm	>0.46
Yb2000-30/400DC	10 dB/m (nominal)	3 ± 0.5dB/m	30 ± 3μm	0.07 ± 0.01	400 ± 15μm	500 ± 15μm	>0.46

PRICE SCHEDULE-Call For Quantities Over 250m

ITEM #	PRICE/m	$	£	€	¥
Yb2000-4/125	1 to 9m	$190.00	£133.00	€190,00	¥ 32,300
	10 to49m	$150.00	£105.00	€ 150,00	¥ 25,500
	50 to249m	CALL	CALL	CALL	CALL
Yb2000-6/125DC	1 to9m	$220.00	£154.00	€ 220,00	¥ 37,400
	10 to 49m	$175.00	£122.50	€ 175,00	¥ 29,750
	50-249m	CALL	CALL	CALL	CALL
Yb2000-30/400DC	1 to9m	$560.00	£392.00	€ 560,00	¥ 95,200
	10 to49m	$450.00	£315.00	€ 450,00	¥ 76,500
	50 to249m	CALL	CALL	CALL	CALL

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EXHIBIT 4

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Chapter 5

Optic Fiber Waveguides

We are now ready to address the major item in our communications system, the optic fibers. Although only a few will ever design and fabricate your own fibers, you should have some idea how it is accomplished. Proper choice and proper utilization require a deep understanding of fiber construction and fiber characteristics. With this in mind, we will study the major types of fibers and the properties of waves propagating through them. We will pay particular attention to attenuation, modes, and information capacity. Construction and design of fibers and fiber cables are also discussed.

5-1 STEP-INDEX FIBER

The *step-index* (SI) fiber[1] consists of a central core whose refractive index is n_1, surrounded by a cladding whose refractive index is n_2. Figure 5-1 illustrates the structure, sometimes referred to as the *step-index matched-clad* fiber. As with the dielectric slab, complete guidance requires that the reflection angle θ be equal to or greater than the critical angle θ_c. The critical angle for the SI fiber is given by

$$\sin \theta_c = \frac{n_2}{n_1} \qquad (5\text{-}1)$$

The *fractional refractive index change* Δ is an important fiber parameter. It is given by

$$\Delta = \frac{n_1 - n_2}{n_1} \qquad (5\text{-}2)$$

This parameter is always positive because n_1 must be larger than n_2 for a critical angle to exist. Typically, Δ is of the order of 0.01.

Efficient transmission requires that the core and cladding be as free of loss as possible. Although the ray diagram implies that the light travels entirely within the core, this is not precisely the case. Actually, some of the light travels in the cladding in the form of an evanescent wave, as discussed in Chapter 4 for the slab waveguide. If the cladding is nonabsorbent, then this light is not lost but travels along the fiber. The evanescent fields decay rapidly, so that no light will reach the edge of the cladding if it is a few tens of microns thick.

The question arises as to the need for the cladding at all. A core of glass surrounded by air satisfies the requirement $n_1 > n_2$, and would indeed guide a light wave. However, severe problems arise when attempting to handle or support this type of structure. Any lossy material attached to the core for support will cause losses in the propagating wave. The freely suspended core could bend or be easily scratched, causing additional losses. The cladding protects the core from contamination and helps preserve its physical integrity.

Step-index fibers have three common forms: a glass core, cladded with a glass having a slightly lower refractive index; a silica glass core, cladded with plastic; and a plastic core, cladded with another plastic. Generally, the refractive-index step is smallest for all-glass fibers, a little larger for the plastic-cladded silica (PCS) fibers, and largest for the all-plastic construction. The all-plastic fiber is often referred to as *polymer optical fiber* (POF). The step sizes are due to the limited range of refractive indices available for glasses and the somewhat larger range for plastics.

As with the slab waveguide, modal distortion and numerical aperture increase with the refractive index difference, $n_1 - n_2$. Because of this, the intermodal pulse spread and NA are small for the all-glass fiber, larger for the PCS fiber, and highest for the all-plastic structure. Fibers with little pulse spread have large rate-length products. The NA of these fibers is small, making it difficult to efficiently couple light into them.

The attenuation loss in an all-glass fiber is generally lower than in a PCS or an all-plastic fiber. All-glass losses of a few dB/km and less are available. PCS fibers have losses around 8 dB/km. All-plastic fibers may have losses of several hundred dB/km.

From the information in the preceding paragraphs, we can reach a number of conclusions regarding the performance and application of the three types of SI fibers. The following statements apply to fibers that are large enough to support many modes:

1. All-glass fibers have the lowest losses and the smallest intermodal pulse spreading. Because of these properties, they are useful at moderately high information rates or fairly long lengths. 30 MHz × km is an achievable rate-length product. The low NA of the SI glass fiber results in large losses when coupling from a light source. The low transmission loss partially compensates for this problem.

   Conventionally, the size of a fiber is denoted by writing its core diameter and then its cladding diameter (both in micrometers) with a slash between them. For example, a 50/125 fiber describes one with a 50-μm core and a 125-μm cladding. Typical dimensions of SI fibers are 50/125, 100/140, and 200/230.
2. Because PCS fibers have higher losses and larger pulse spreads than all-glass fibers, they are suitable for shorter links.

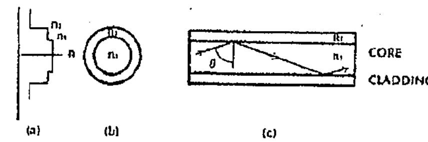

Figure 5-1 Step-index fiber. (a) Refractive index profile. (b) End view. (c) Cross-sectional side view.

Their higher numerical apertures increase the source coupling efficiency, but this advantage is lost in a long fiber owing to increased absorption. PCS fibers are normally suitable choices when the path lengths are less than a few hundred meters. Core diameters of 200 μm are typical for PCS fibers. The large core diameter improves the source coupling efficiency.

3. All-plastic fibers are limited to very short paths by their high propagation losses. Path lengths are usually less than a few tens of meters. Large cores and large numerical apertures make plastic fibers usable because of the resulting high coupling efficiencies. Core diameters as large as 1 mm are typical.

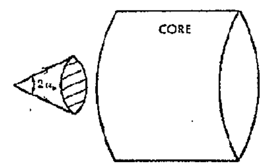

Figure 5-2 Acceptance cone for trapping of light by a step-index fiber.

Numerical apertures, acceptance angles, and fractional refractive-index changes for fibers representative of all-glass, PCS, and all-plastic constructions are listed in Table 5-1. The numerical apertures and acceptance angles were computed from Eq. (4-21), NA = $\sin\alpha_o = \sqrt{n_1^2 - n_2^2}$, assuming that air surrounded the input end of the fiber. Since the core and cladding refractive indices are nearly equal for most all-glass fibers, the approximate result NA = $n_1\sqrt{2\Delta}$ is valid for them. Only rays emitted within a cone having a full angle $2\alpha_o$ will be trapped by an SI fiber, as illustrated in Fig. 5-2. Typical LEDs and laser diodes emit light over a wide angular range, often larger than the acceptance angles in Table 5-1. The numerical results in Table 5-1 show the clear advantage of a fiber having a larger NA, and thus a larger acceptance angle, for improved light collection. In Section 8-5 we consider the source-fiber coupling losses quantitatively.

Review of the step-index structure indicates that light can also be trapped by total internal reflection at the outer boundary of the cladding if the material surrounding the cladding has a lower refractive index than the cladding itself. Figure 5-3 illustrates the possible ray paths. In the example shown, the ray angle at the core-cladding interface is less than the critical angle, so some light is transmitted into the cladding. This light strikes the outer surface of the cladding beyond the critical angle for that boundary and totally reflects back toward the fiber axis. The light represented by this ray never leaves the fiber and is thus guided by it. This example illustrates the existence of cladding modes. Cladding modes are characterized by rays traveling along paths that cross the fiber axis at angles greater than those of the modes guided by the core. They are excited by light introduced into the fiber end at angles beyond the acceptance angle. They also begin at discontinuities, such as splices and connectors, where light may be deflected beyond the core-mode angles.

TABLE 5-1. Typical Step-Index Fiber Characteristics

Construction	n_1	n_2	NA	α_0	Δ
All-glass	1.48	1.46	0.24	13.9°	0.0135
PCS	1.46	1.4	0.41	24.2°	0.041
All-plastic	1.49	1.41	0.48	29°	0.054

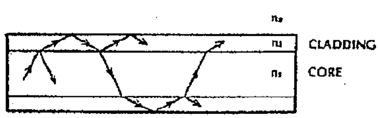

Figure 5-3 Ray paths of cladding modes. At the core-cladding interface there is partial reflection, accounting for the multiple ray paths.

The light traveling in a cladding mode attenuates more rapidly than light in a core mode because the outer boundary of the cladding is normally in contact with a lossy material. In addition, small bends in the fiber reduce the ray angle below that for total reflection, causing radiation losses. We can often observe power in cladding modes at points close to the light source. This power attenuates so rapidly that the cladding modes are insignificant at the end of a long fiber.

Example 5-1

Suppose that the glass fiber in Table 5-1 is surrounded by air. Compute the critical angle at the cladding-air boundary.

Solution:

Again by using the critical-angle equation, we find $\theta_c = \sin^{-1}(1/1.46) = 43°$. This should be compared with a core mode, where $\theta_c = \sin^{-1}(1.46/1.48) = 80.6°$. Recalling that θ is the ray angle as measured from the boundary normal, we can see how much more steeply the cladding-mode rays travel, relative to the fiber axis, than the core-mode rays.

Cladding modes are eliminated in some fibers by coating the cladding with a material having a refractive index equal to, or greater than, that of the cladding itself. In such a fiber, referred to as one with a *matched buffer*, a critical angle does not exist at the outer boundary of the cladding.

5-2 GRADED-INDEX FIBER

The *graded-index* (GRIN) fiber has a core material whose refractive index decreases continuously with distance from the fiber axis. This structure, illustrated in Fig. 5-4, appears to be quite different from the SI fiber. We will show how the GRIN fiber guides light by trapping rays, not unlike the operation of a SI waveguide. The index variation is described by[2]

$$n(r) = n_1\sqrt{1 - 2(r/a)^\alpha\Delta}, \quad r \le a \qquad (5\text{-}3a)$$

$$n(r) = n_1\sqrt{1 - 2\Delta} = n_2, \quad r > a \qquad (5\text{-}3b)$$

where

n_1 = refractive index along the fiber axis
n_2 = refractive index outside the core (cladding index)
a = core radius
α = parameter describing the refractive-index profile variation
Δ = parameter determining the scale of the profile change

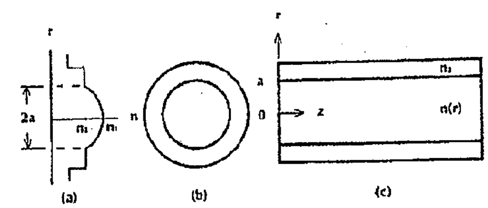

Figure 5-4 Graded-index fiber. (a) Refractive-index profile. (b) End view. (c) Cross-sectional view.

sures the location of splices, connectors, and breaks.

An example of a system power-budget calculation follows, although a more detailed system design discussion is presented in Chapter 12.

Example 5-4

A fiber system operates at a wavelength of 1300 nm where the fiber loss is 0.5 dB/km. The LED light source emits 1.59 mW and couples with a 16-dB loss into the fiber. Connectors and splices in the system contribute a total loss of 6 dB. The *receiver sensitivity* (the power required for the receiver to detect the message with a specified error rate or signal-to-noise ratio) is given as − 30 dBm. A 4-dB margin is specified to account for system degradations (such as aging of the LED). What is the maximum length of fiber that can be used?

Solution:

It is often convenient to perform power-budget calculations in dBm and dB. The LED power of 1.59 mW equals 2 dBm. Table 5-2 summarizes the power-budget calculations.

The maximum allowable fiber length is then 6/0.5 = 12 km.

TABLE 5-2. Sample Power-Budget Calculations

LED output power		2 dBm
Receiver sensitivity		−30 dBm
Loss budget		32 dB
Coupling loss	16 dB	
Connector and splices	6 dB	
Power margin	4 dB	
Total losses	26 dB	−26 dB
Available fiber loss		6 dB

5-4 MODES IN STEP-INDEX FIBERS

The mode chart for step-index fibers appears in Fig. 5-17. This chart is similar to the symmetrical slab mode chart in Fig. 4-5. One difference is that the fiber chart has been normalized by plotting the effective refractive index as a function of the parameter V. V, called the *normalized frequency*, is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2} \qquad (5\text{-}7)$$

where a is the core radius and λ is the free-space wavelength. By using V, a single chart can be drawn that applies for any combination of values of a, λ, n_1, and n_2. As the propagation characteristics that can be deduced from the SI mode chart are discussed, note the many features common to wave travel in the fiber and in the slab.

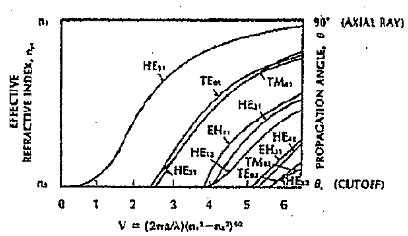

Figure 5-17 Mode chart for step-index fibers. (The HE_{11} mode cuts off at $V = 0$.) (From Donald B. Keck, "Optical Fiber Waveguides," in *Fundamentals of Optical Fiber Communications,* 2d ed., Michael K. Barnoski, ed., New York: Academic Press, Inc., 1981, p. 18. Reproduced with permission.)

The chart shows the existence of many modes. TE and TM modes are the transverse electric and transverse magnetic modes as defined in Section 4-2. HE and EH modes are hybrid, and both contain components of electric and magnetic fields pointing along the fiber axis. Each curve in Fig. 5-17 actually represents two modes, one orthogonally polarized with respect to the other in the transverse plane.

Conventional fibers do not preserve the polarization of the launched wave. Since orthogonally polarized waves associated with the same mode have the same effective refractive indices, they travel at the same velocity and easily couple energy between themselves. This exchange occurs at bends, twists, splices, and any other mechanical deformation of the fiber.

The effective refractive indices for all modes lie between the index of the cladding and that of the core. For a given mode, n_{eff} varies with wavelength, producing waveguide dispersion. At a fixed value of V, several modes may propagate, each having a different effective index. This condition leads to modal distortion. The longitudinal propagation factor can be obtained from n_{eff} by applying Eq. (4-6), $\beta = k_0 n_{eff}$. Ray angles are determined from Eq. (4-7).

Propagation in the fiber is quite similar to propagation in the slab. As with the slab, modes are cut off when their rays travel at the critical angle, and rays far from cutoff travel close to 90° almost directly down the fiber. In addition, decaying evanescent fields exist outside the core for all of the modes; and the closer a mode comes to cutoff, the deeper its wave penetrates into the cladding. Far from cutoff, a propagating wave travels almost entirely in the core.

For large values of V, many modes will propagate. Large V corresponds to a relatively large core radius. When $V > 10$, the number of modes (including all polarizations) is approximated by[6]

$$N = \frac{V^2}{2} \qquad (5\text{-}8)$$

Example 5-5

Compute the number of modes for a fiber whose core diameter is 50 μm. Assume that $n_1 = 1.48$ and $n_2 = 1.46$, as was done for the all-glass fiber in Section 5-1. Let $\lambda = 0.82$ μm.

Solution:

The value of V, from Eq. (5-7), is

$$V = \frac{2\pi(25)}{0.82}\sqrt{1.48^2 - 1.46^2} = 46.45$$

Then, from Eq. (5-8), we find that there are 1078 modes.

It is clear from this example that even a moderately small fiber can support a large number of modes. Because the normalized frequency is proportional to the difference in refractive indices of the core and cladding, keeping this difference small reduces the number of propagating modes.

The lowest-ordered mode for the SI fiber is the HE_{11} mode. Its transverse field pattern, drawn in Fig. 5-18, is approximately Gaussian shaped. That is, the power distribution in the

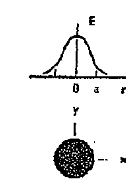

Figure 5-18 Transverse pattern for the lowest-ordered mode in the SI fiber, the HE_{11} mode.

transverse plane is approximated by the Gaussian intensity pattern given by Eq. (2-15). The Gaussian approximation is good when the V parameter is between 1.8 and 2.4, the region where (for reasons to be discussed in the next few paragraphs) most single-mode fibers are designed to operate.

The spot size (also frequently called the *mode-field radius*) of the equivalent Gaussian beam is given in terms of the normalized frequency by the expression[7]

$$\frac{w}{a} = 0.65 + 1.69V^{-3/2} + 2.879V^{-6} \qquad (5\text{-}9)$$

This expression, valid for the range $1.2 < V < 2.4$, is plotted in Fig. 5-19. Note that as the V parameter decreases below 2.4, the spot size increases and eventually becomes much larger than the core radius. In other words, for small values of V the light beam extends significantly beyond the core and into the cladding. In this condition the beam is not as tightly bound to the core and is highly susceptible to bending losses. For this reason, single-mode fibers are normally operated with a value of V in the neighborhood of 2–2.4. Values of V close to 2.4 are avoided to minimize the chances of propagation of more than just one mode.

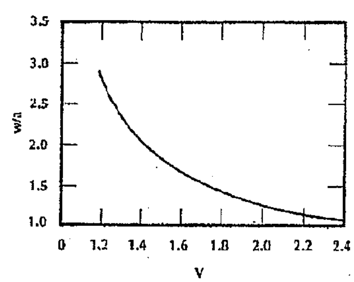

Figure 5-19 Normalized spot size w/a for the lowest-ordered mode in a step-index fiber.

Single-mode propagation is assured if all modes except the HE_{11} mode are cut off. Referring to Fig. 5-17, this occurs if $V < 2.405$. Combining this result with Eq. (5-7) yields

$$\frac{a}{\lambda} < \frac{2.405}{2\pi\sqrt{n_1^2 - n_2^2}} = \frac{2.405}{2\pi \cdot (NA)} \qquad (5\text{-}10)$$

as the condition for single-mode propagation. This result is very similar to the single-mode condition for the symmetrical slab, Eq. (4-17). If Eq. (5-10) is satisfied, then only the HE_{11} mode may travel through the fiber. Two orthogonally polarized HE_{11} waves can actually exist in the fiber simultaneously, but they have the same n_{eff} and, therefore, travel at the same velocity. This characteristic is more important than the fact that there are actually two modes in most applications.

An exception to this rule occurs when the fiber exhibits significant *birefringence*. Birefringence refers to the phenomenon where the refractive index depends on the direction of wave polarization. Birefringence occurs because of the lack of perfect circular symmetry in the refractive index. This lack of symmetry arises because the fiber may not be perfectly circular *(geometrical birefringence)* and because of unequal stresses built into the fiber *(stress birefringence)*. With birefringence the wave velocity *will* depend upon the direction of polarization. Thus the two orthogonally polarized HE_{11} waves will not travel at the same speed. This is a small effect in conventional single-mode fibers. It is enhanced in single-mode *polarization-preserving fibers*, which are designed to maintain the polarization of the launched wave. Polarization is preserved because the two possible waves have significantly different propagation characteristics. This keeps them from exchanging energy as they propagate through the fiber.

Polarization-preserving fibers are constructed by designing asymmetries into the fiber.[8] Examples include fibers with elliptical

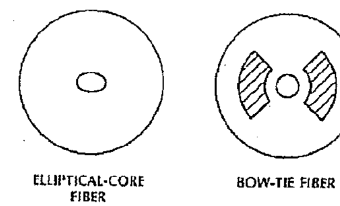

Figure 5-20 Polarization-preserving fibers.

cores (which cause waves polarized along the major and minor axes of the ellipse to have different effective refractive indices) and fibers that contain nonsymmetrical stress-producing parts. These are illustrated in Fig. 5-20. The shaded region in the bow-tie fiber is highly doped with a material such as boron. Because the thermal expansion of this doped region is so different from that of the pure silica cladding, a nonsymmetrical stress is exerted on the core. This produces a large stress-induced birefringence, which in turn decouples the two orthogonal modes of the single-mode fiber.

Polarization-preserving fibers are required in several applications. These include the fiber optic gyroscope and coherent optical detection systems (these applications are discussed in Section 10-5).

Still another special fiber is the *polarizing fiber*. This single-mode fiber allows only one of the two orthogonally polarized HE_{11} modes to propagate. It does so by designing the asymmetry in the fiber such that the undesired polarization state has a higher attenuation than that of the desired state. These fibers can be used to produce polarized light when the source is unpolarized.

Polarization control in conventional, polarization-preserving, and polarizing fiber is illustrated in Fig. 5-21. In (a) a conventional fiber, the output polarization is unknown regardless of the input polarization state because of random coupling between all the polarizations present. In (b) a polarization-preserving fiber maintains the polarization of a polarized input wave but cannot polarize an incoming unpolarized beam. In (c) a polarizing fiber will pass just one of the polarizations present in an unpolarized input and will maintain the polarization of an input polarized in the preferred direction of the fiber polarizer. An input polarized in the nonpreferred direction will not be propagated.

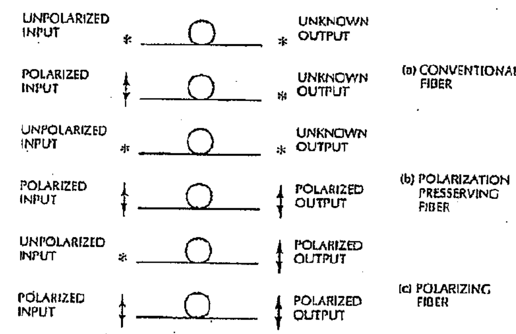

Figure 5-21 Polarizing effects of a conventional, polarization-preserving, and polarizing fiber.

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EXHIBIT 5

QUANTUM ELECTRONICS—PRINCIPLES AND APPLICATIONS

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To Haide, Christina and Mikel

2.2 Guided Modes of the Optical Fiber

All dielectric waveguides support a finite number of guided modes in addition to the infinite continuum of radiation modes that are not guided by the structure but are, nevertheless, solutions of the same boundary value problem. We begin the approximate analytical treatment of round optical fibers by deriving the guided modes of the structure.

Marcatili realized that the description of the modes of the weakly guiding fiber becomes much simpler if the components of the field vectors are expressed in rectangular cartesian coordinates instead of the cylindrical coordinates that appear so much more suitable to the cylindrical geometry of the waveguide.

The cross section of the optical fiber is shown in Fig. 2.2.1. Region 1 with refractive index n_1 is the fiber core, region 2 with index n_2 is the cladding. In all our work we assume that the cladding is infinitely extended, in spite of the fact that it has a finite radius for practical fibers. The justification for assuming an infinitely extended cladding region comes from the fact that the guided modes have exponentially decaying fields outside the core. If the cladding radius is large enough, the guided mode fields have decayed to insignificant values at the outer boundary of the cladding. All practical fibers are designed to ensure that the guided mode field does not reach the outer boundary of the cladding. In the opposite case the fiber would suffer high radiation losses, since the outer fiber surface is never perfectly smooth on account of accumulating dust and other environmental effects.

The assumption of an infinite cladding radius is more questionable when we study the radiation modes. These solutions of the boundary value problem

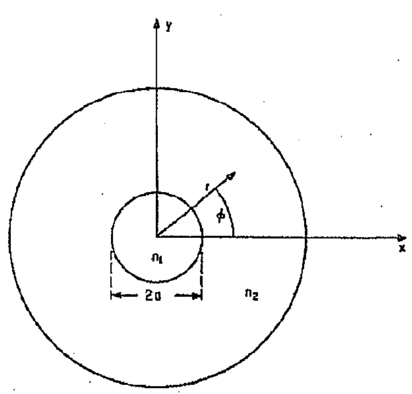

Fig. 2.2.1 *Cross section of a round optical fiber.*

reach out to infinity with undiminished strength and are certainly strongly affected by the outer cladding boundary. However, we can justify our procedure even for the radiation modes. The finite radius of the cladding has the effect of trapping some of the radiation field, causing cladding modes to appear. These modes have a discrete spectrum of allowed values of their propagation constants. But the density of these modes is much higher than the core modes, so that they form almost a continuum. When we calculate the interaction of the core modes with the radiation modes of the fiber with infinite cladding, we must keep in mind that in actuality we would have coupling of the core modes and the cladding modes. The fact that a portion of the radiation field does not actually escape freely but finds itself trapped by reflection at the outer cladding boundary does not alter our conclusions very much. In most practical cases cladding modes will be suppressed by a lossy coating on the outside of the fiber, or they will scatter out of the cladding on account of the rough outer surface. In either case, power will not endure very long in cladding modes and may be considered as being lost, just as it would be had it radiated away freely. In those cases where these conditions are not met it is necessary to study the interaction of core and cladding modes in detail.

The derivation of the simplified guided modes of the fiber uses again the longitudinal E_z and H_z components from which the transverse components are derived by means of Eqs. (1.7-4)–(1.7-7). The longitudinal components must satisfy the reduced wave Eq. (1.7-9) which we now express in cylindrical coordinates:

$$\frac{\partial^2\psi}{\partial r^2} + \frac{1}{r}\frac{\partial\psi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\psi}{\partial\phi^2} + K_j^2\psi = 0 \qquad (2.2\text{-}1)$$

with

$$K_j^2 = n_j^2k^2 - \beta^2 \qquad (2.2\text{-}2)$$

and

$$k = \omega(\varepsilon_0\mu_0)^{1/2} = 2\pi/\lambda \qquad (2.2\text{-}3)$$

Equation (2.2-1) is obtained from Maxwell's equations by eliminating the transverse field components and solving Maxwell's equations for either E_z or H_z. All field components have the common factor

$$\exp[i(\omega t - \beta z)] \qquad (2.2\text{-}4)$$

which we omit from the equations for brevity.

To solve the reduced wave equation we substitute the trial solution

$$\psi = F(r)\cos\nu\phi \qquad (2.2\text{-}5)$$

the infinite cross section. We obtain the same relation for all four types of modes:

$$A = \left[\frac{4(\mu_0/\varepsilon_0)^{1/2}\gamma^2 P}{e_\nu \pi a^2 n(n_1{}^2-n_2{}^2)k^2 |J_{\nu-1}(\kappa a)J_{\nu+1}(\kappa a)|}\right]^{1/2} \tag{2.2-42}$$

with

$$e_\nu = \begin{cases} 2, & \text{for} \quad \nu = 0 \\ 1, & \text{for} \quad \nu \neq 0 \end{cases} \tag{2.2-42a}$$

A derivation of this formula is given at the end of this section.

The eigenvalue Eq. (2.2-39) must be solved by numerical techniques. However, near cutoff and far from cutoff of each mode, approximate closed-form solutions can be worked out. Near cutoff we have the inequality

$$\gamma a \ll 1 \tag{2.2-43}$$

We can thus use the approximations of the Hankel functions for small arguments. For $\nu = 0$, we use

$$H_0^{(1)}(i\gamma a) = (2i/\pi)\ln(\Gamma\gamma a/2) \tag{2.2-44}$$

with

$$\Gamma = 1.781672 \tag{2.2-45}$$

For $\nu \neq 0$, the following approximation holds:

$$H_\nu^{(1)}(i\gamma a) = -[i(\nu-1)!/\pi](2/i\gamma a)^\nu \tag{2.2-46}$$

Substitution of these relations into Eq. (2.2-38) yields, for $\nu = 0$,

$$\gamma a = (2/\Gamma)\exp[-(1/\kappa a)J_0(\kappa a)/J_1(\kappa a)] \tag{2.2-47}$$

At cutoff we have $\gamma a = 0$ and $\kappa_c d = V_c$. This last relation follows from

$$(\kappa^2+\gamma^2)a^2 = V^2 = (n_1{}^2-n_2{}^2)k^2a^2 \tag{2.2-48}$$

We thus obtain the cutoff condition for $\nu = 0$ modes from Eq. (2.2-47):

$$J_1(V_c) = 0 \tag{2.2-49}$$

It is apparent from Eq. (2.2-48) that near cutoff we have, to a good approximation,

$$\kappa a \approx V_c + (V-V_c) - [(\gamma a)^2/2V_c] \tag{2.2-50}$$

so that we finally find the near cutoff approximation for $\nu = 0$ modes [neglecting the $(\gamma a)^2$ term in Eq. (2.2-50)]

$$\gamma a = \frac{2}{\Gamma}\exp\left[-\frac{1}{V}\frac{J_0(V)}{J_1(V)}\right] \tag{2.2-51}$$

For the modes with $\nu = 1$ we obtain from Eqs. (2.2-39), (2.2-44), and (2.2-46),

$$\kappa a J_0(\kappa a)/J_1(\kappa a) = (\gamma a)^2 \ln(\Gamma\gamma a/2) \tag{2.2-52}$$

The cutoff condition for $\nu = 1$ modes is thus

$$J_0(V_c) = 0 \tag{2.2-53}$$

We use Eqs. (2.2-50) and (2.2-53) and expand the function $J_0(\kappa a)$ with the help of the functional relation for the derivative of Bessel functions,

$$J_\nu'(\kappa a) = -(\nu/\kappa a)J_\nu(\kappa a) + J_{\nu-1}(\kappa a) = (\nu/\kappa a)J_\nu(\kappa a) - J_{\nu+1}(\kappa a) \tag{2.2-54}$$

(where the prime indicates the derivative with respect to the whole argument) obtaining

$$J_0(\kappa a) = -[(V-V_c)-(\gamma a)^2/2V_c]J_1(V_c) \tag{2.2-55}$$

If we now replace κa with V_c on the left-hand side of Eq. (2.2-52) and substitute Eq. (2.2-55), we obtain, for modes with $\nu = 1$,

$$(\gamma a)^2 = 2V_c(V-V_c)/[1-2\ln(\Gamma\gamma a/2)] \tag{2.2-56}$$

This is still an implicit equation for γa, but it can easily be solved with a few iterations. V_c is obtained as the solution of Eq. (2.2-53).

To find the approximation for $\nu \geq 2$ we expand $J_{\nu-1}(\kappa a)$ with the help of Eqs. (2.2-50) and (2.2-54) and the cutoff condition

$$J_{\nu-1}(V_c) = 0, \qquad \text{for} \quad \nu = 2, 3, \ldots \tag{2.2-57}$$

and obtain

$$J_{\nu-1}(\kappa a) = -[(V-V_c)-(\gamma a)^2/2V_c]J_\nu(V_c) \tag{2.2-58}$$

Equations (2.2-39) and (2.2-50) thus yield the near cutoff approximation for all modes with $\nu \geq 2$

$$\gamma a = \{2[(\nu-1)/\nu]V_c(V-V_c)\}^{1/2} \tag{2.2-59}$$

V_c is obtained as the solution of Eq. (2.2-57). The roots of the Bessel functions which solve Eqs. (2.2-49), (2.2-53), and (2.2-57) can be found in tables of Bessel functions [Jel, As1]. In Eq. (2.2-51) we did not expand the Bessel function $J_1(V)$ as we did in the other equations. The reason is twofold: The usual expansion of the type (2.2-55) or (2.2-58) would not work for the $V = 0$ solution of Eq. (2.2-49), since the expression $J_1(V_c)/V_c = 0/0$ is encountered in Eq. (2.2-54) for $V_c = 0$. It is, of course, easy to determine the limit of this undetermined ratio. The easiest approach would be to use the small argument approximation

$$J_\nu(V) = (1/\nu!)(V/2)^\nu \tag{2.2-60}$$

Appl. No. : **09/785,944**
Filed : **February 16, 2001**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Martin E. Fermann
Appl. No.	:	09/785,944
Filed	:	February 16, 2001
For	:	MODE-LOCKED MULTI-MODE FIBER LASER PULSE SOURCE
Examiner	:	Hrayr A. Sayadian
Group Art Unit	:	2828

DECLARATION UNDER 37 C.F.R. § 1.132 OF MARTIN E. FERMANN AND DONALD J. HARTER

1. The undersigned Martin E. Fermann is the sole inventor of the above-captioned patent application.

2. The undersigned Martin E. Fermann and Donald J. Harter are the two named inventors of U. S. Patent No. 5,818,630.

3. The inventions defined by Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 of the above-captioned patent application are the sole invention of Martin E. Fermann.

4. To the extent that the inventions defined by Claims 1, 7, 13, 14, 16-18, 22, 23, 25, 30-32, 35-38, 46, and 50 of the above-captioned patent application are disclosed in U. S. Patent 5,818,630, the inventions were derived from Martin E. Fermann.

5. We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like

so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of the application or any patent issued thereon.

Respectfully submitted,

Dated: 12.20.2006 By: ______________
Martin E. Fermann

Dated: 12/20/06 By: ______________
Donald J. Harter

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APPENDIX 3

IMRAA.015C1

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Martin E. Fermann
Appl. No.	:	09/785,944
Filed	:	February 16, 2001
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Group Art Unit	:	2828

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DECLARATION UNDER 35 USC 1.132 OF
MARTIN E. FERMANN AND DONALD J. HARTER

1. The undersigned Martin E. Fermann is the sole inventor of the above-captioned patent application.

2. The undersigned Martin E. Fermann and Donald J. Harter are the two named inventors of U. S. Patent 5,818,630.

3. The invention defined by Claims 55 and 57 of the above-captioned patent application is the sole invention of Martin E. Fermann.

4. To the extent that the invention defined by Claims 55 and 57 of the above-captioned patent application is disclosed in U. S. Patent 5,818,630, it was derived from Martin E. Fermann.

5. We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like

Appl. No.	:	**09/785,944**
Filed	:	**February 16, 2001**

so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of the application or any patent issued thereon.

Respectfully submitted,

Dated: 1.10.2006

By: Mart E.F.
Martin B. Fermann

Dated: 1/10/06

By: DJ Harter
Donald J. Harter

2053748
110805

X. RELATED PROCEEDINGS APPENDIX

None

XI. ASSIGNMENT APPENDIX

The present application is a continuation of parent U.S. Patent Application No. 09/199,728, now U.S. Patent No. 6,275,512. The entire right, title, and interest to the parent application and all continuations thereof was assigned by the inventor Martin E. Fermann to IMRA America, Inc. by virtue of the assignment attached hereto as **Appendix 4**, and recorded by the Assignment Division of the U.S. Patent and Trademark Office at Reel 9914, Frame 0989 on April 26, 1999 (the Notice of Recordation is also included in Appendix 4).

APPENDIX 4

4440059
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ASSIGNMENT

WHEREAS, I, Martin E. Fermann, a citizen of Germany, residing at 4931 Ravine Court, Ann Arbor, MI 48105, have invented certain new and useful improvements in a MODE-LOCKED MULTI-MODE FIBER LASER PULSE SOURCE for which I have filed an application for Letters Patent in the United States, Application No. 09/199,728, filed on November 25, 1998;

AND WHEREAS, IMRA AMERICA, INC. (hereinafter "ASSIGNEE"), a Michigan Corporation, with its principal place of business at 1044 Woodridge Avenue, Ann Arbor, MI 48105, desires to acquire the entire right, title, and interest in and to the said improvements and the said Application:

NOW, THEREFORE, in consideration of the sum of One Dollar ($1.00) to me in hand paid, and other good and valuable consideration, the receipt of which is hereby acknowledged, I, the said inventor, do hereby acknowledge that I have sold, assigned, transferred and set over, and by these presents do hereby sell, assign, transfer and set over, unto the said ASSIGNEE, its successors, legal representatives and assigns, the entire right, title, and interest throughout the world in, to and under the said improvements, and the said application and all divisions, renewals and continuations thereof, and all Letters Patent of the United States which may be granted thereon and all reissues and extensions thereof, and all rights of priority under International Conventions and applications for Letters Patent which may hereafter be filed for said improvements in any country or countries foreign to the United States, and all Letters Patent which may be granted for said improvements in any country or countries foreign to the United States and all extensions, renewals and reissues thereof; and I hereby authorize and request the Commissioner of Patents of the United States, and any Official of any country or countries foreign to the United States, whose duty it is to issue patents on applications as aforesaid, to issue all Letters Patent for said improvements to the said ASSIGNEE, its successors, legal representatives and assigns, in accordance with the terms of this instrument.

AND I HEREBY covenant and agree that I will communicate to the said ASSIGNEE, its successors, legal representatives and assigns, any facts known to me respecting said improvements, and testify in any legal proceeding, sign all lawful papers, execute all divisional, continuing and reissue applications, make all rightful oaths and generally do everything possible to aid the said ASSIGNEE, its successors, legal representatives and assigns, to obtain and enforce proper patent protection for said improvements in all countries.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this 14th day of April 1999.

M. E. F.
Martin E. Fermann

STATE OF MICHIGAN
COUNTY OF WASHTENAW] ss.

On APRIL 14, 1999, before me, PHYLLIS A. McLAUGHLIN, personally appeared Martin E. Fermann personally known to me (or proved to me on the basis of satisfactory evidence) to be the person whose name is subscribed to the within instrument, and acknowledged to me that he executed the same in his authorized capacity, and that by his signature on the instrument the person, or the entity upon behalf of which the person acted, executed the instrument.

WITNESS my hand and official seal.

[SEAL] PHYLLIS A. MCLAUGHLIN
Notary Public, Washtenaw County, MI
My Commission Expires Oct. 7, 2002

Phyllis A. McLaughlin
Notary Signature

IMRAH.015A

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ASSIGNOR:
FERMANN, MARTIN E.

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ANN ARBOR, MICHIGAN 48105

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